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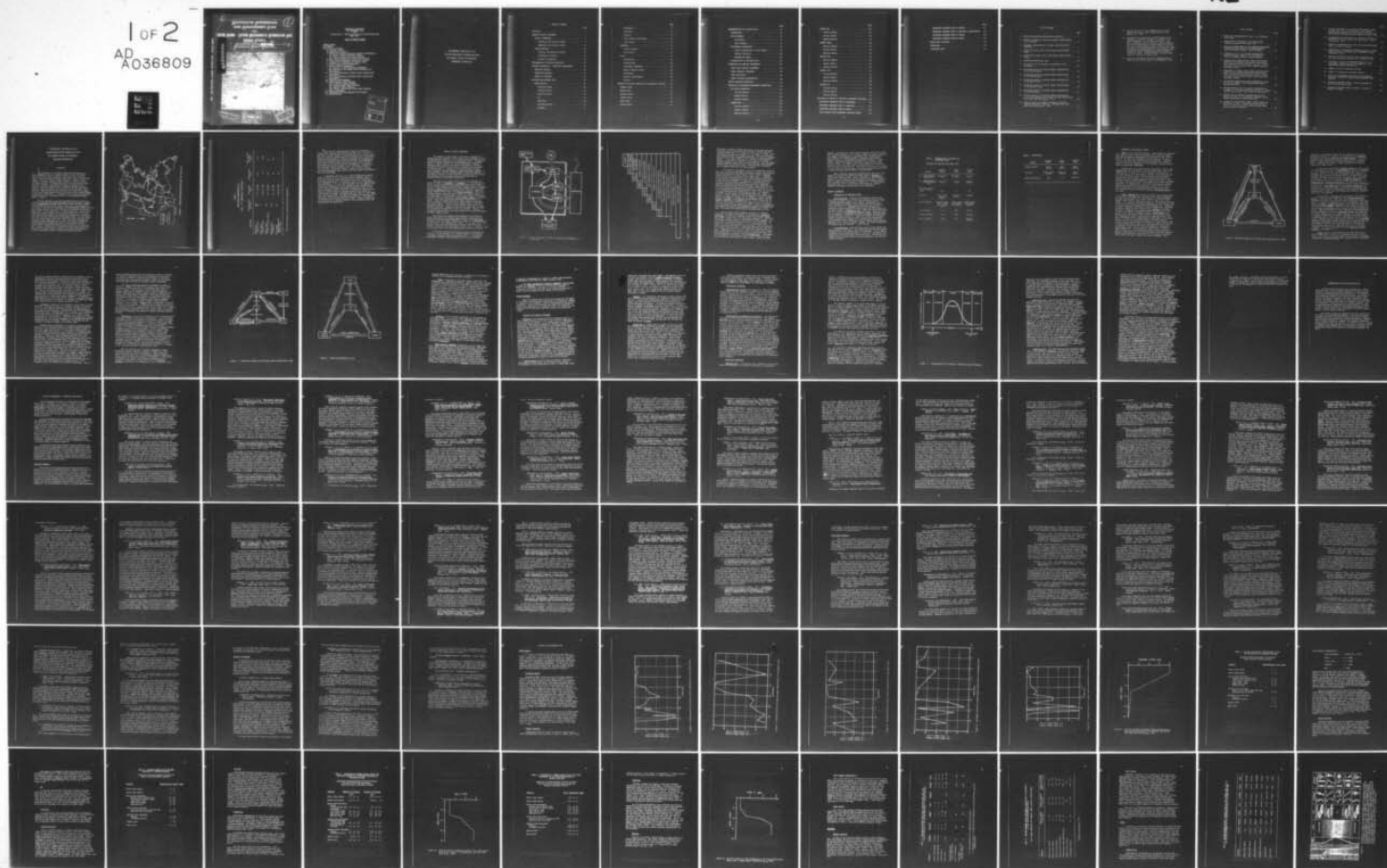
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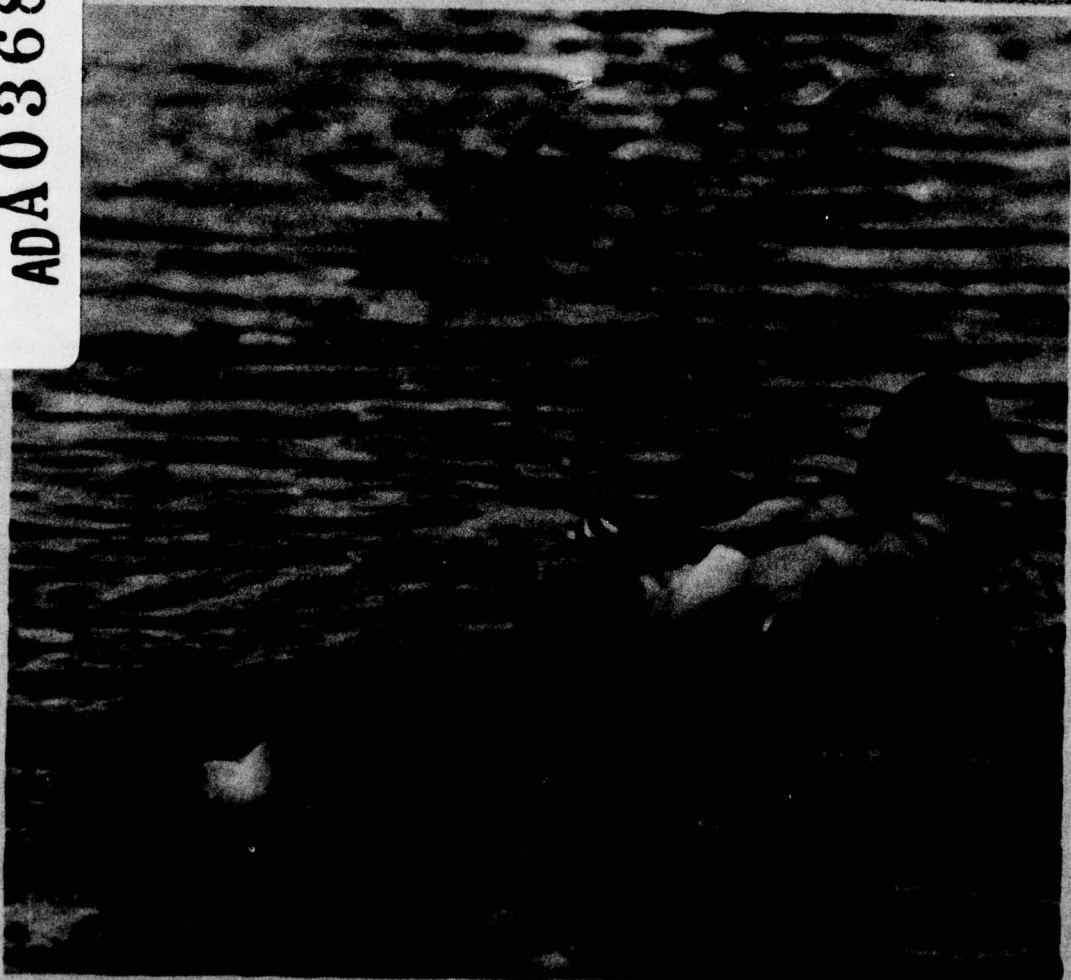
BOSTON HARBOR - EASTERN MASSACHUSETTS METROPOLITAN AREA

EMMA STUDY.

TECHNICAL DATA ~~XXXXXXXXXX~~ Volume 13A.
BIOLOGICAL IMPACT ANALYSIS.

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WASTEWATER ENGINEERING
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FOR
Boston Harbor - Eastern Massachusetts Metropolitan Area
EMMA STUDY

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ENVIRONMENTAL CONDITIONS IN THE
EASTERN MASSACHUSETTS METROPOLITAN AREA
AND PROBABLE IMPACTS OF WASTEWATER
MANAGEMENT ALTERNATIVES

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ENVIRONMENTAL CONDITIONS IN THE
EASTERN MASSACHUSETTS METROPOLITAN AREA
AND PROBABLE IMPACTS OF WASTEWATER
MANAGEMENT ALTERNATIVES

OBJECTIVE

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The waterways of the Eastern Massachusetts Metropolitan Area (~~Figure 1~~) consist of Boston Harbor, a large (47 square miles) relatively shallow complex of bays and tidal estuaries, with 180 miles of tidal shoreline; plus three rivers of substantial length: the Charles River (length, 80 miles), Neponset River (length, 30 miles) and Mystic River (length, 17 miles including its major tributary, the Aberjona River). Outlying regions along the coast include: river and tidal estuarine systems of the Ipswich, Pines and Saugus Rivers; Gloucester, Beverly and Salem Harbors on the North Shore; and the Jones, North and South Rivers and Gulf, Cohasset and Scituate Harbors on the South Shore. The total area of land drained by all of the above water systems amounts to some 1274 square miles. A breakdown of River Basin drainage and stream flow for the five major rivers in the Metropolitan area is shown in Table 1.

Various portions of the area described above have been continuously occupied by European man for more than 340 years. During this time the region has been subjected to ever increasing amounts of municipal wastes and other abuses. Two of the three rivers in the central area have been impounded over considerable portions of their length and now constitute a series of freshwater and brackish water lakes. This alteration of a river system which in some cases ostensibly improves water quality by restricting salt water incursion, has not been without its detrimental consequences. Upstream pollutants are not effectively carried beyond dams. In Lower Mystic Lake and Lower Charles River Basin especially toxic materials have built up in the bottom waters over time. The recent installation of modern sewage treatment facilities at Deer and Nut Islands in Boston Harbor have transplanted much of the pollution load to marine waters, thereby alleviating some pressures on the tributaries. However, infiltration of sewage into storm water runoff (especially via combined sewer systems) and scores of unidentified illicit discharges continue to degrade freshwater quality.

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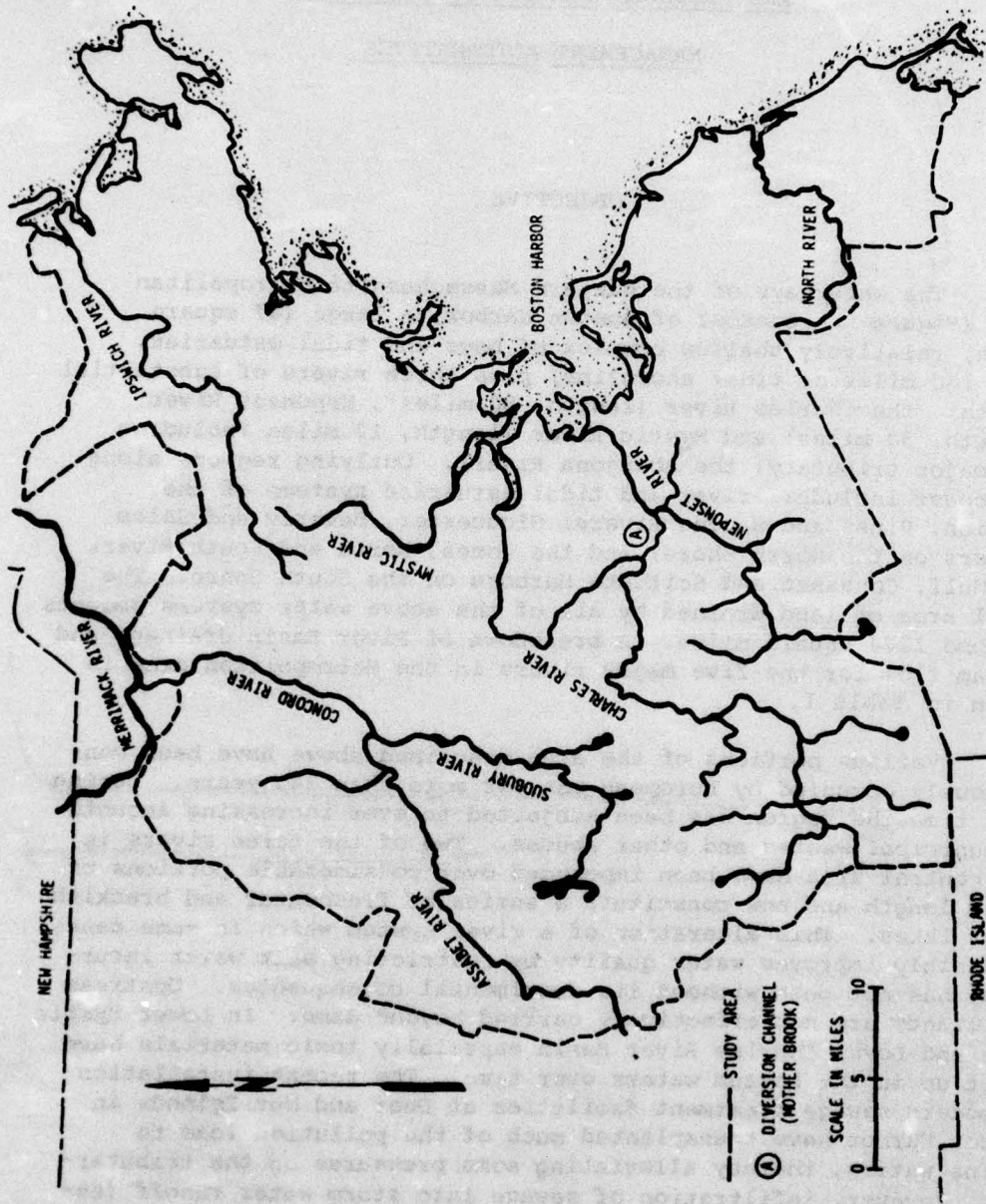


Figure 1. Eastern Massachusetts Metropolitan Study Area.

TABLE 1.
RIVER BASIN CHARACTERISTICS
(from: U.S. Geological Survey Data)

Watershed	Drainage Area (sq. mi.)	Flow Range (cfs)	Average Flow (cfs)	7 day, 10 year Low Flow (cfs)
North Shore Ipswich River	422 155	0.8 to 2600	198	1.8
Mystic River Aberjona River	73	0.25 to 835	27	0.42
Charles River @ Charles River Village	315	0.9 to 3220	370	11
Neponset River @ Norwood	132	0.6 to 1790	50	4.9
South Shore Indian Head River (North River)	332	0.23 to 1390	60	*

* less than 10 years of record has been accumulated

↓
Corrective and remedial measures have been proposed, ranging from elaborate and expensive schemes, such as the construction of large tunnels in rock under the City of Boston into which all combined (sewage and storm) overflows can be discharged through vertical shafts; to simple solutions, such as repair of broken and malfunctioning tide gates (designed to exclude salt-water from inundating sewer lines during high tides). A real need exists for rapid and efficient evaluation of the impact of such proposed solutions so that the environmental consequences may be weighed against economic costs. As a partial step in this direction, the present study is aimed at evaluating both existing environmental data and the need for further environmental data collections. ↙

A subsequent objective is to specify appropriate environmental criteria for use in evaluating the ecological impact of alternative municipal and regional pollution abatement plans which are presently being considered as part of a larger wastewater management study. In developing the criteria, consideration has been given to: 1) the need to predict how local aquatic and terrestrial communities will be affected by the implementation of the various wastewater management alternatives; and 2) the need to determine whether any short or long term biological problems will persist after the designed quantity and quality of liquid waste and sludge, discharged upon the land or in the waterways, has been reached. The specified impact criteria were selected from a larger list of parameters and chemical constituents recognized as having some biological impact. Upper or lower limits of tolerance, or growth responses, are considered where such designations are appropriate.

GENERAL APPROACH CONSIDERED

The approach we have taken in the present assessment of metropolitan area resources is one based on the ecosystem, not in the mathematical sense but in its conceptualization. Thus we have viewed the Eastern Massachusetts Metropolitan area as a complex system of inputs, outputs, and cyclical phenomena, together producing what we perceive as today's "environment". Physical and chemical "inputs" are fed into the system at various points in time and space -- a change in the kind and amount of each input causing a sometimes dramatic, oftentimes subtle response in the environment. As the study develops, we deal with smaller and smaller "systems" to the point where ultimately, only singular land entities and point-source aquatic discharges must be reckoned within the wastewater evaluations.

That part of the planet Earth in which living forms are active is called the biosphere or ecosphere. It is characterized chiefly by the availability of substantial quantities of water and an abundant supply of energy from an external source (ultimately the sun). Solar energy enters the biotic component of the system through chlorophyll bearing organisms (some bacteria, algae and higher plants) collectively termed primary producers. Beyond the primary producers there are two consumer food chains (Figure 2). One chain begins with the grazing or browsing animals (herbivores) and continues on to successively higher trophic levels of predatory animals. The other consists of organisms of decomposition or decay. These are basically primitive forms (molds, fungi, and various microbes) which derive their energy from the breakdown of dead organic matter. The two chains function side by side and frequently overlap, in that products from one chain may be transferred to the other. Energy is lost at each step, from the reception of the sun's energy to the last step of decay. Figure 3 illustrates schematically the stepwise decrease in energy available to higher trophic levels.

When functioning properly the biosphere is in a state of dynamic equilibrium, in which energy and matter constantly move through the system without appreciably disrupting the status quo or steady state conditions. Except for energy, all other essentials for maintaining life processes are cycled. In the water cycle, for example, evaporation over the ocean is greater than the direct return by precipitation, the reverse is true on land. The ocean deficit and land surplus is rectified by runoff return from streams.

Differences between terrestrial and aquatic ecosystems are profound. On land virtually all primary producers are attached or closely associated with the substrate (soil). In the aquatic environment, however, light penetrates only a short distance.

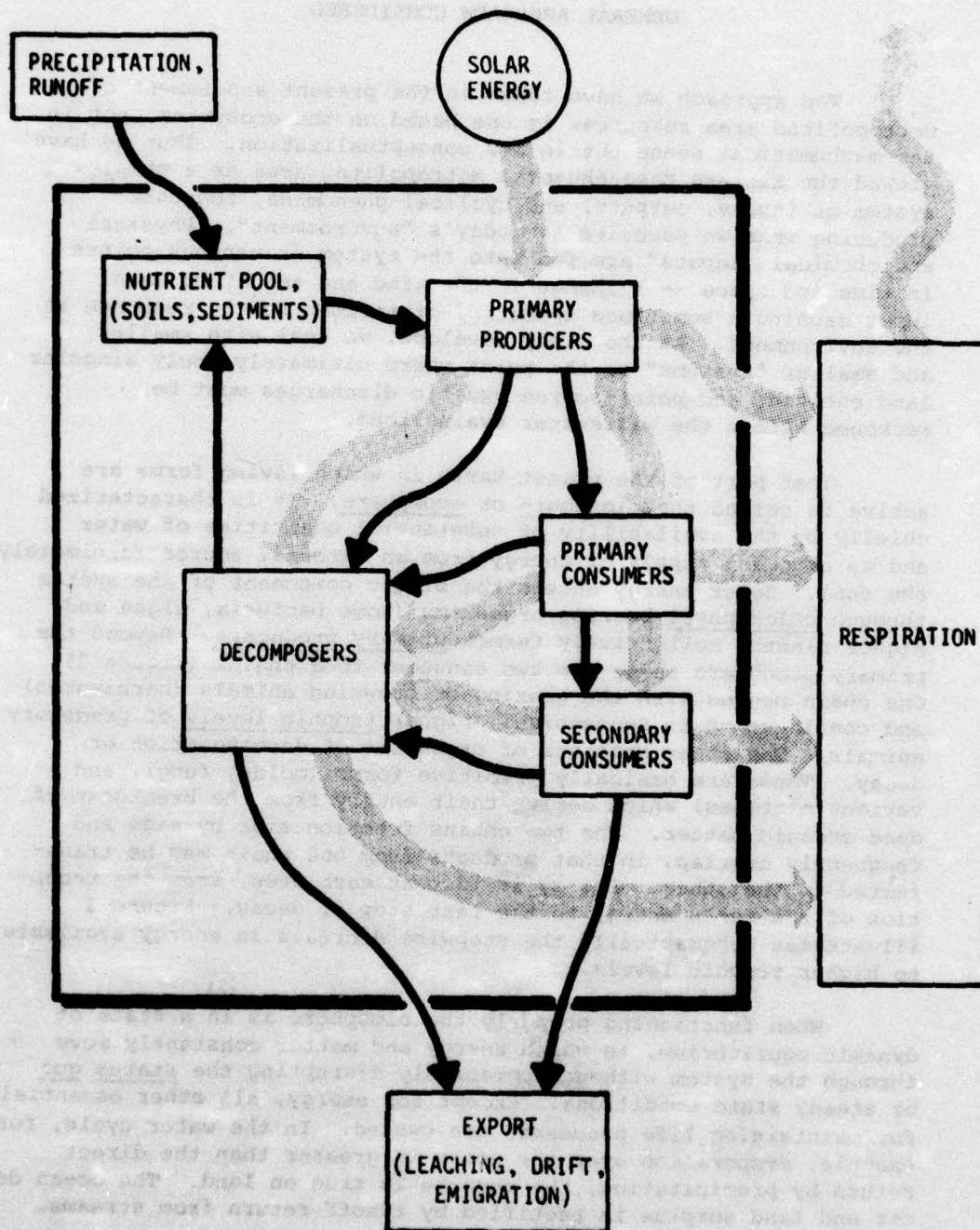


Figure 2. Schematic diagram of energy and nutrient relationships in an ecosystem.

Figure 3. Schematic representation of energy utilization by an ecosystem.

Therefore, the bulk of primary production (by the phytoplankton) takes place very close to the water surface, removed from the sediments where much of the essentials for life are stored. Most organisms associated with sediments in the aquatic environments are consumers rather than primary producers. On land the consumer biomass is very small compared to the biomass of photosynthetic plants. In the aquatic environment the biomass of consumer organisms surpasses the biomass of phytoplankton. The tiny aquatic primary producers support the relatively enormous animal biomass through rapid division and growth. Producer bulk is normally kept to modest proportions by animal grazers.

In terrestrial ecosystems, recycling of materials essential for life is tightly controlled, especially in mature forest growth. Most land plants have the capacity to retain (store) essential organic materials (in leaves, fruits, stems, etc.). Inorganic salts are also ionically bound to the vast network of root hairs. In the aquatic environment, however, cycling of many materials is intermittent and sometimes not completed. Availability of the essential nutrients which accumulate in the bottom sediments depends on fortuitous patterns of advection (e.g. upwelling) to bring the materials into the sunlit surface layers where they can be assimilated by phytoplankton and recycled. Consequently, the store of undecomposed and decaying matter under water is characteristically proportionately larger than on land. For complete breakdown and utilization of undecomposed materials, oxygen is required. Under certain conditions organisms in the decay chain exhaust the supply of oxygen. In the absence of oxygen, decomposition is incomplete, and products of incomplete decay, such as methane, cyanides, and sulfides build up. Vital connections between the decay chain and the animal consumer chain are reduced or broken and ecosystem integrity is lost. Aquatic ecosystems are more susceptible to the above sequence of events than terrestrial ecosystems, particularly since molecular oxygen (O_2) is only about one-fortieth as concentrated in aerated water as in air.

Due at least in part to under utilization of sediment resources, the aquatic environment is vulnerable to ecological succession, by which the biosphere advances or develops toward more stable (controlled), self regulating communities. Succession progresses through a series of developmental stages (seres). In the absence of catastrophic intervention (e.g., glaciation, sea level rise) successional pressure is on the conversion from aquatic to terrestrial systems, not vice versa. When the flow of energy and other essentials is completely open and "once-through", as in freely flowing streams, the successional sequence does not apply. Impounded waters, however, "age" at varying rates, depending in particular on the rate of input of organic and other life essential material (a process called eutrophication). Development of a terrestrial system from an aquatic system begins with submerged vegetation and continues (seral stages: floating leaved,

emergent, saturated soil, sedge-meadow, thicket, moist soil, brush land, fringing woodland) until a mature community evolves consistent with edaphic characteristics (topography, soil characteristics, water supply) and climatic factors. A parallel successional sequence occurs in the progression from barren ground to climax growth. Freshwater aquatic environments are in reality a very scarce resource. The world's fresh water comprises only three percent of the total water supply; three quarters of it is in the form of polar ice and glaciers. Only about two percent of the water in liquid form is found in lakes, rivers and similar smaller bodies of water (the remaining 98 percent is ground water).

When a carefully balanced ecosystem breaks down (as in the example of insufficient oxygen described above) a senescent or dying stage usually ensues. Such occurrences are becoming more frequent in a biosphere increasingly dominated by man's influence. Table 2 compares attributes and tendencies of developing, mature and senescent stages of ecological communities. In the following paragraphs many of the factors which have important roles in community development and destruction are considered.

ABIOTIC SUBSTANCES

Substances with Physical Impact

Solid Particles. Insoluble solid material disturbs the ecosystem by blanketing or covering the energy receiving surfaces of primary producers (such as the leaves of higher plants). It is particularly detrimental in the aquatic environment since light penetration is further reduced from what may already be a critically low level. Turbidity measures the scattering of penetrating light caused by the smaller particles which persist in the water column as suspended solids. Larger and heavier particles settle on the bottom (settleable solids) as silt. Here they also act as a blanket, inhibiting physical and chemical exchange across the sediment-water interface. Substantial changes in the bottom sediment characteristics, as a result of silting, may devastate certain bottom faunal communities by providing the medium for accumulation of noxious materials, and by clogging the respiratory apparatus (e.g., gills) of aquatic animals. On land the emergence of seedlings may be inhibited by heavy silting.

Oily Substances. Physical harm is done by oil through the coating action of oil films. Such films may interfere with gaseous exchange between the organism and its environment. In the aquatic environment the air-water interface is especially vulnerable since oxygen may be prevented from entering the water. The heavier the surface coating and the lighter the water movements, the worse the situation becomes.

TABLE 2. CHARACTERISTIC ATTRIBUTES OF ECOSYSTEM STAGES

(Adapted and modified from Odum, 1971)

ATTRIBUTE	DEVELOPING STAGES	MATURE STAGE	SENESCENT STAGE
Ratio: $\frac{\text{gross production}}{\text{community prod.}}$	greater than one	approximately one	less than one
Ratio: $\frac{\text{gross production}}{\text{standing crop biomass}}$	greater than one	less than one	much less than one
Annual yield (new additions to standing crop)	high	low	low
Food chains	simple, direct grazers predominate	intricate, web like	disrupted
Nutrient resources	internal control loose, high reliance on outside sources	internal control tight, nearly self sufficient	controls breakdown, nutrients released
Species diversity	low	high	very low
Biochemical diversity	low	high	very high
Role of decomposers	minor	major	dominating function

Table 2. (Continued)

ATTRIBUTE	DEVELOPING STAGES	MATURE STAGE	SENESCENT STAGE
Community structure	loosely organized	well organized	poorly organized
Niche space	broad, loosely defined	narrow, well defined	open to invasion
Competitive pressures	high	low	seldom occur

Substances with Chemical Impact

Water is the "universal solvent". Hence nearly all materials which come in contact with the biosphere have a chemical impact, since they dissolve to some degree and thus interact with living tissues. It would be a monumental task to cover all, or even most, of the substances incorporated into ecosystems. Consideration will be given below only to those materials with critical impact on the living components of the ecosystem, especially with regard to wastewater management.

Liquid water is an ionic solution and always contains some hydrogen ions since the water itself can supply them. pH is the logarithm (to the base 10) of the reciprocal of hydrogen ion concentration. A scale from zero to fourteen is established such that zero represents a concentration fourteen orders of magnitude greater than fourteen. In a terrestrial environment soil moisture may give a reading from pH 3 (very acid) to pH 10 (very alkaline), but most plant communities exist in soil with a moisture pH within a few units of pH 6. The permissible range for aquatic communities is somewhat more restricted. In the marine environment the pH range for living organisms is about 7 to 9. This shift of about two units toward alkaline pH comes about due to the chemical activities of greater amounts of dissolved solids in the ocean.

Carbon Compounds are the fuel as well as the building material for life. Photosynthetic organisms create organic compounds by fixing carbon dioxide (CO_2) (see Figure 4). The generalized formula is as follows: $\text{CO}_2 + 2\text{H}_2\text{A} + \text{light} = \text{CH}_2\text{O} + \text{H}_2\text{O} + 2\text{A} + \text{energy}$. The A usually represents oxygen (O), but may also represent sulfur (S), a portion of an organic compound, or even nothing at all (in which case the H_2A becomes molecular hydrogen, H_2). Consumers of organic compounds (including the plants themselves) release the chemically stored energy by combusting or oxidizing the organic molecule. Ultimately this requires oxygen to complete the chain of reactions (release of maximum energy). Oxygen demand is a measure of the quantity of oxygen required to release the energy and decompose the material contained in an aqueous medium. The more undecomposed organic matter present, the higher is the oxygen demand. In practice the oxygen demand is measured either by oxidizing all of the combustible material in a water sample to CO_2 (Chemical Oxygen Demand, COD), or incubating a sample of the water in specially designed bottles for a given period of time under standardized conditions of bacterial decomposition (Biochemical Oxygen Demand, BOD). BOD has special significance in tracing septic conditions. To the non-public health oriented biologist, however, oxygen demand is less meaningful than other more specific measures of movements of essentials for life through the system. Total content of organic carbon (TOC) may be measured. The

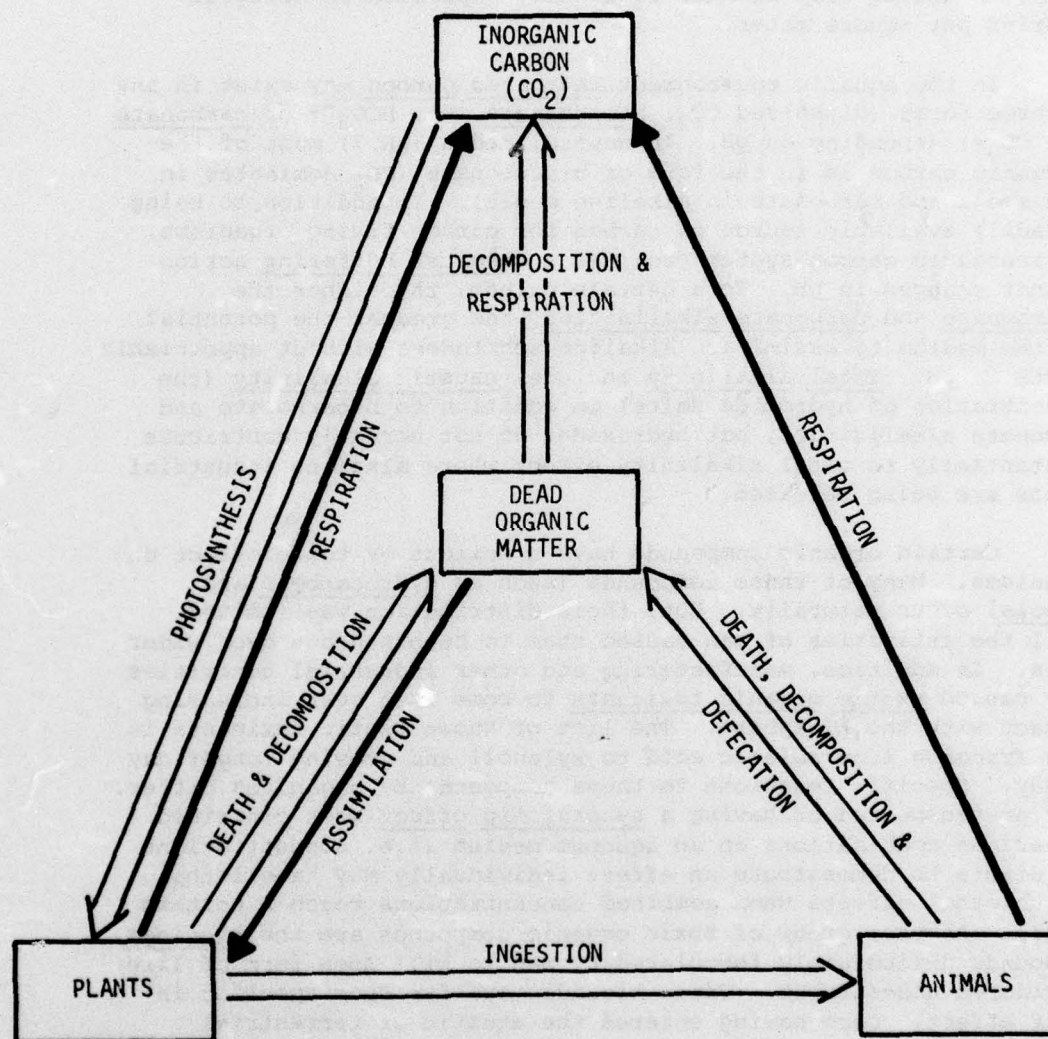


Figure 4. Simplified carbon cycle (broad arrows indicate major loops)

activity of the primary producers may be followed by the use of radioactive tracers (e.g. Carbon 14), measurement of chlorophyll a concentration and the light and dark bottle method. All of the measures can be expressed as rates of carbon fixation or energy flow (in kilogram calories per square meter per given period of time). Standing crop biomass is usually expressed as kilogram calories per square meter.

In the aquatic environment inorganic carbon may exist in any of three forms (dissolved CO_2 ; bicarbonate ion, HCO_3^- ; or carbonate ion, CO_3^{2-}) depending on pH. In neutral media (pH 7) most of the inorganic carbon is in the form of bicarbonate (CO_2 dominates in acid media and carbonate in alkaline media). In addition to being a readily available source of carbon for carbon fixing organisms, the inorganic carbon system provides a chemical buffering action against changes in pH. To a certain extent, the higher the bicarbonate and carbonate alkalinities, the greater the potential for the medium to assimilate alkaline substances without appreciable shifts in pH. Total alkalinity includes caustic alkalinity (the concentration of hydroxide salts) in addition to bicarbonate and carbonate alkalinities, but hydroxides do not normally contribute substantially to total alkalinity except where alkaline industrial wastes are being released.

Certain organic compounds have a noxious or toxic effect on organisms. Many of these compounds (such as hydrocarbons and phenols) occur naturally. But, their distribution was limited until the activities of man caused them to be broadcast over wider areas. In addition, manufacturing and other industrial activities have caused exotic organic toxicants to come into ever increasing contact with the biosphere. The list of known exotic toxicants is long (ranging from abietic acid to xylenol) and growing longer day by day. Specific reactions to these compounds by organisms differ. Many are suspected of having a synergistic effect when contained in various combinations in an aqueous medium (i.e. concentrations too dilute to demonstrate an effect individually may have lethal or sublethal effects when combined concentrations reach a certain level). Another group of toxic organic compounds are the biocides, compounds deliberately formulated by man to kill some form of life considered undesirable. Often biocides are far from specific in their effect. Once having entered the aquatic or terrestrial ecosystem the potential for injury may be carried to desirable organisms. The well documented case of the chlorinated hydrocarbons is one example.

Oxygen appears in many chemical forms and combinations. Certain aspects of its role in the biosphere have been treated above. The content of available oxygen in the aquatic environment is measured as dissolved oxygen (DO). Oxygen content is governed

not only by factors affecting exchange with the atmosphere (such as temperature, dissolved solids and turbulent mixing) but by the photosynthetic activity and respiration of plants and animals. With the sun high overhead, in relatively clear waters, production of O_2 exceeds consumption in a thriving phytoplankton population; DO values are relatively high. By nightfall, however, photosynthesis has ceased; both plants and animals consume the oxygen surplus built up during the day. Just prior to dawn, oxygen values in a lake or slow moving stream are usually at their lowest. The diurnal oxygen curve (generated from continuous or periodic DO readings over a 24-hour period) can be used to quantify the productive activity of a quiet water aquatic community. DO readings approaching zero in the bottom waters indicate a disrupted consumer chain and the build up of products of incomplete decomposition when such readings persist for extended periods of time.

Nitrogen is required in the formation of proteins by primary producers. Although nitrogen is an abundant element, the bulk of it is in a form (gaseous molecular nitrogen, N_2) unusable by all but a very few forms of life. Nitrogen must be fixed (chemically incorporated into a compound) before it is usable. Until industrial fixation processes were developed, most of the nitrogen fixation was accomplished by terrestrial organisms, often living in close association with higher plants. Freshwater blue-green algae, marine microorganisms, and ionizing phenomena in the atmosphere (lightning, radiation) also fix nitrogen. Terrestrial ecosystems have the capacity to conserve nitrogen in its usable forms.

Primary producer organisms of the aquatic ecosystem (phytoplankton) do not have much storage or holding capacity because of their small size and mass (which allows them to remain longer in the sunlit upper water layers). In the aquatic environment selection has favored mechanisms of quick response to the availability of usable nitrogen (e.g. from products of decomposition in the sediments). Generation times of phytoplankton are very short. Some diatoms, for example can treble their population size in less than 24 hours. Even a seemingly small (few parts per million) increase in usable nitrogen may initiate a bloom under the proper conditions (temperature, light, etc.). Blooms are periods of high phytoplankton density resulting from intensified reproductive activity; they occur periodically under natural conditions and are usually quite harmless and perhaps even vital to the survival of other forms of aquatic life. Occasionally, however, a bloom develops into a pathological condition. Perhaps a certain species capable of producing toxic substances may dominate temporarily; or an unusually large bloom goes into a sudden decline, levying a heavy burden on the consumer chain. Animal grazers may not reproduce fast enough to crop the phytoplankters before they die. The load of dead and dying plants is shifted solely to the decomposer chain with implications discussed previously. Thus, a

vitally necessary nutrient has the capacity to choke off the life it sustains, a prospect which has received more and more attention since the advent of large scale manufacture of synthetic fertilizers and concentration of domestic waste into the rather restricted space occupied by freshwater aquatic ecosystems.

The cycle of nitrogen through the biosphere is shown in Figure 5. Ammonia (NH_3) excreted by animals and produced as an end product of the decay chain is assimilated most readily by plants. However, when released in very large quantities as ammonium hydroxide in industrial wastes it has an immediate toxic effect. Some cold water fish (salmon, trout) are sensitive to substantial accumulations of ammonia in the bottom waters where they normally live, but invertebrates and plants are relatively tolerant. In the absence of ammonia, plants take up nitrate (NO_3^-) which is typically the most abundant usable form of nitrogen in soil or water. Nitrite (NO_2^-) is typically a transient form and is least abundant. Concentration of dissolved nitrate is a conventional measure of the nitrogen free of higher plant control and available for use in producing more living tissue. In a stable, mature ecological community, such as is found in most terrestrial and marine environments, the amount of "excess" nitrogen should be minimal.

Phosphorous is the scarcest commodity of the "macronutrients" (substances required in more than trace amounts). The chief uses of phosphorous are in the skeletal structures of animals (storage) and in the transfer and transport of chemical energy in the form of high energy phosphate bonds (as in adenosine triphosphate, ATP). A simplified scheme of phosphorous cycling is presented in Figure 6. The scarcity of this element requires the same economics to operate as in the case of nitrogen. In fact, phosphorous metabolism appears to be intimately linked to nitrogen. Both elements are scarce; but nitrogen is required in far greater quantities (about fourteen to sixteen atoms of nitrogen are required for every atom of phosphorous). Where overall production is low, the factor limiting plant growth is usually phosphorous (nitrogen in the form of ammonia and nitrate is available in sufficient amounts). However, in cases such as artificial over enrichment or eutrophication, where overall production is much higher, "the relationship is reversed and the sources of nitrogen act as the limiting factor" (Vollenweider, 1971).

When the standing crop of aquatic organisms is large, phosphorous storage capacity is adequate to supply the minute quantities needed for future generations. Living organisms contain enormous quantities of phosphorous compounds compared to normal levels found in many types of environments. In the marine environment, for example, the exchange of phosphorous from organism to organism is so rapid that levels of inorganic phosphate (principally as orthophosphate, PO_4^-) dissolved in the

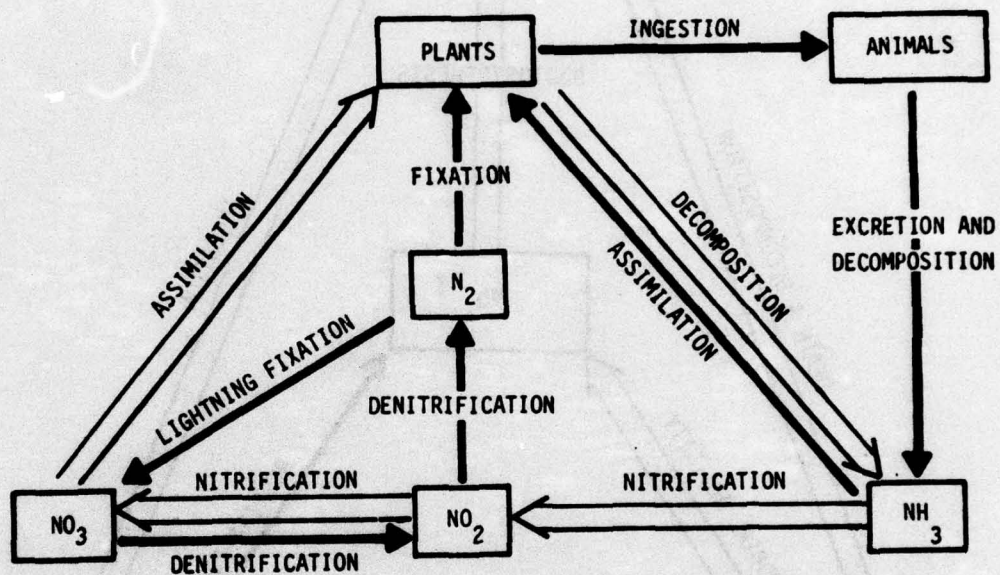


Figure 5. Simplified nitrogen cycle (broad arrows indicate major loop)

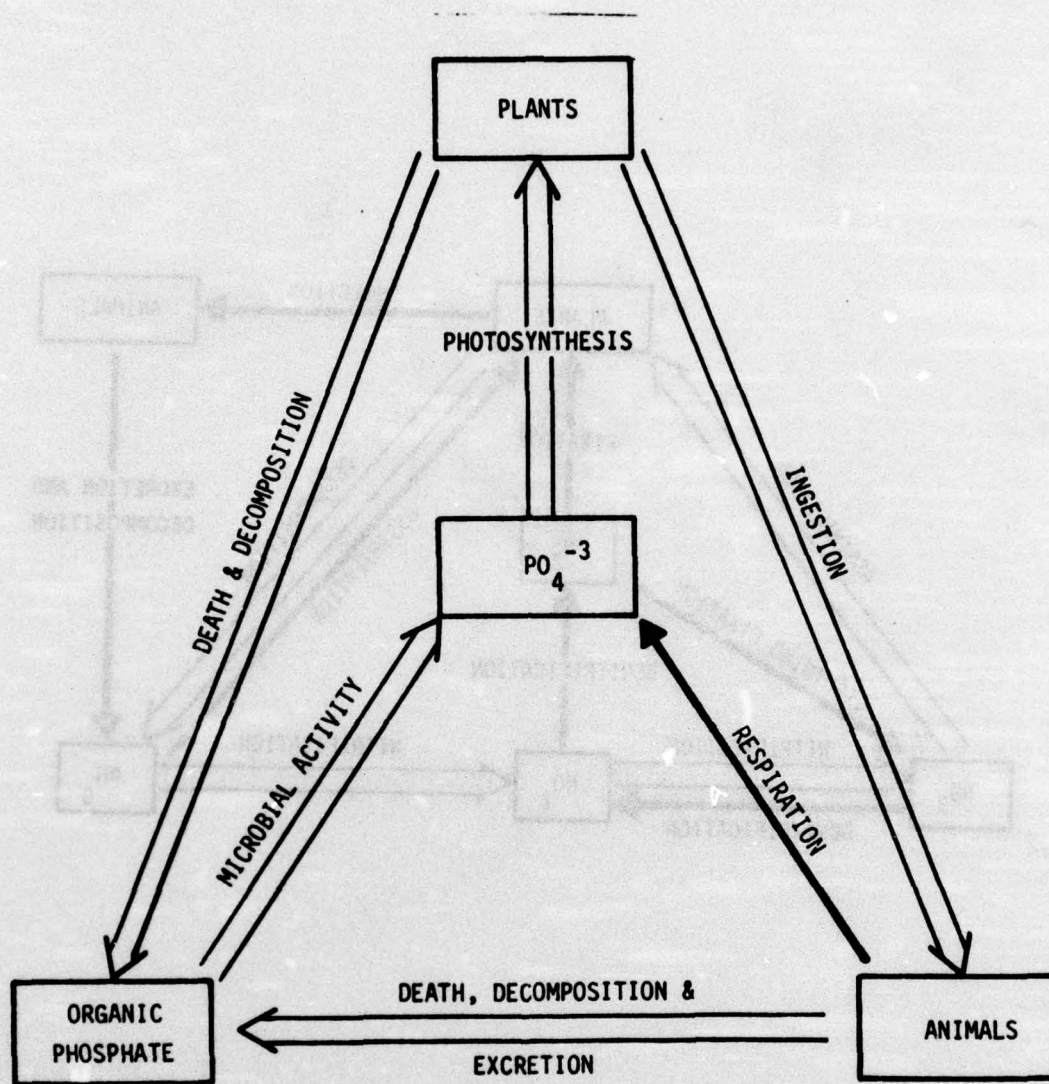


Figure 6. Simplified phosphorous cycle.

external medium are often too small to measure with any degree of accuracy with instruments presently available.

Sulfur is required in very small amounts (even less than phosphorous) to form sulfide groups in certain amino acids. Sulfide to sulfide bonds maintain the critical shape of a protein molecule, allowing it to fold and unfold in a manner commensurate with its specific function. Sulfur is available to primary producers in sufficient quantities as sulfate ($\text{SO}_4^{=}$) and sulfide ($\text{S}^{=}$). In the absence of oxygen, sulfur substitutes as an oxidizing agent in organic decomposition. Impounded bottom waters often have considerable stores of sulfide from the accumulation of decomposed living tissue (protein). In aquatic environments where ferrous iron is available most of the sulfide is bound as ferrous sulfide (FeS) which provides much of the black color of reduced muds. Substantial quantities of hydrogen sulfide (H_2S) build up only under dystrophic conditions (disrupted ecosystems and acid bogs). Hydrogen sulfide is nearly insoluble in water and rapidly escapes into the atmosphere when a body of water "turns its bottom". Aquatic organisms are extremely sensitive to even the tiny amounts of H_2S dissolved in water. H_2S can act as an environment cue and as an avoidance signal to organisms requiring aerobic conditions for survival.

Chlorine is not a natural constituent of the biosphere as a gaseous element. In its ionic form, chloride, however, is the most common dissolved constituent of natural waters and a major contributor to salinity, specific conductance and dissolved solids. The principal ecological significance of chloride is in the maintenance of osmotic balance (organisms expend metabolic energy to maintain a solute concentration gradient between the interior and exterior of cells). This physiological role is shared with other major ionic constituents in the aqueous medium (chiefly the cations, sodium, potassium, and calcium, which also control reflex responsiveness and neuromuscular functions in animals). Free available chlorine dissolved in an aqueous medium is extremely toxic. Chlorine added to nitrogenous wastes (as a disinfectant may combine with ammonia to form highly toxic and persistent chloramines).

Trace metallic compounds include many, such as copper and zinc, known to be vital to life in minute quantities. Most metal salts exhibit toxic properties when present in quantities many times the natural or background levels. Mining and manufacturing activities have made some metal salts, which were previously never of any consequence in the biosphere, prevalent hazards. Once in the biosphere toxic metals do not necessarily behave as a class. Certain metal salts (e.g. zinc) have their centers of distribution in polluted sediments, whereas, others (e.g. chromium) appear to concentrate in certain portions of the biota (chromium in plankton, Phelps, et.al., 1973). Hardness, attributable chiefly

to calcium and magnesium ions, appears to afford some protection against metallic ion toxicity (McKee and Wolf, 1963).

A few toxic non-metallic inorganic compounds, such as those of boron and selenium, do not fit into any of the categories above. Such compounds, like many of the toxic compounds considered, have historically had rather limited distribution in nature, until the advent of man's industrial activities.

SYSTEM RESPONSES

There are various ways in which the availability and impact of the abiotic variables considered above can be modified, limited, or enhanced in the biosphere. Some of these processes are abiotic themselves. Others are biochemical and geophysical processes in which living organisms are an important link. In a third set, the responses of the organisms themselves, provide the pathway for change.

Physical and Chemical Processes

Overturn is the process by which a freshwater body (i.e. a lake or deep reservoir) recirculates and vertically mixes water layers from various depths. It is accomplished by a combination of winds blowing across the surface and seasonal changes in temperature. The thermal contribution to overturn stems from the fact that pure water is most dense at about 39°F, yet it remains liquid to 32°F. In temperate regions many lakes overturn twice a year, once during spring, when water temperatures at the surface (near 39°F) become denser than at the bottom (below 39°F), and in autumn, when cooling temperatures also make the surface waters denser than the warmer bottom layers. Overturn is a time of rejuvenation for the aquatic ecosystem -- bottom waters are re-aerated and the surface water primary producers receive a renewed supply of nutrients from bottom decomposition. An equivalent process which results from upwelling occurs seasonally in the marine environment. In impounded water bodies with fresh surface waters and brackish or saline bottom waters, overturn is especially difficult because the dissolved solids increase density and make the body of water resistant to mixing. Such water bodies rarely, if ever, overturn. When and if they do (e.g. during an unusually long period of very strong autumn winds) the consequences may be temporarily catastrophic, because of the accumulated products of incomplete decomposition during the years of no overturn.

Stratification is the reverse of overturn. When heat (above 38°F in fresh waters) is introduced at the surface of a standing or slow moving body of water, it makes upper water

layers much less dense than lower layers. The impedance to vertical flow thus created is called thermal resistance to mixing. Thermal stratification is not normally an attribute of streams, except where there are dams or barely flowing areas (backwater pools) along the stream course. Stratification can be intensified by discharges of effluent many of which are substantially warmer than the ambient water. In addition to providing a warm "plume" at the surface, the heated effluent may impede reaeration of the water layers below. In a stream heated effluents should enter where there is sufficient turbulent flow to overcome thermal resistance to mixing.

Leaching. In a terrestrial environment leaching begins with water (usually from precipitation or irrigation) penetrating into the soil. Soluble soil constituents which are in excess of the amount that can be bound to root hairs or soil particles are carried downward with gravity. In a mature ecosystem leaching is held to a minimum by metabolic activity in the roots. A concentration gradient is maintained such that fluids in the plant contain more solutes than the soil moisture. Changes in soil chemistry (e.g. pH or the relative amounts of physiologically active ions such as calcium, potassium, sodium and chloride) can materially affect the ability of the soil-plant system to retain and absorb such scarce ions as nitrate and phosphate. In dry porous soil, the leachate may percolate past the soil horizon and enter the ground water. In wet or poorly drained soil the leachate may leave the system as runoff.

Stream flow is a major means of export of materials from both terrestrial and freshwater ecosystems. Marine ecosystems are the ultimate importers. Communities within a free flowing stream are unique in that they must cope with a completely open ended energy and nutrient flow. There is little possibility of recycling within the stream itself. Flow rate is an important criterion because it provides the stream with the capacity to assimilate and dilute transported substances. Under natural conditions the volume of stream flow reflects trends in the surplus of precipitation over evaporation. Streams typical of the New England Region are usually swollen in the spring from melting ice and snow, plus heavy rainfall. By August, however, the surplus of precipitation over evaporation has been eliminated by warm temperatures and strong sunlight; streams usually shrink to their lowest levels at this time. Summer is often the time of greatest biological activity in a freely flowing stream, not only because of the warm temperatures but also because nutrient substances are concentrated by the low volume. By the same token, this is the period of greatest single potential impact on the river ecosystem by human activities.

Chemical complexation accounts for the strong correlation between the accumulation of organic materials in sediments and the concentration of many toxic metallic salts. A number of metal ions form chelated (Greek chela, claw) complexes with organic chemical groups (e.g. amine groups, NH_2 and organic sulfides).

Biochemical Processes

Biogeochemical cycling is the process by which the chemical constituents of life circulate as elements or in various compounds between organisms and their environment. The overall cycle can be separated conceptually into its various subunits, also called cycles. The much simplified cycles shown in Figures 4, 5, and 6 indicate the circulation of carbon, nitrogen, and phosphorous. Each cycle indicates the chemical processes of living organisms (formation, alteration and decomposition of organic compounds) and the chemical processes of the inanimate portion of the biosphere (formation and transport of inorganic compounds). Ecological imbalance resulting from excess accumulation of certain materials, such as carbon and nitrogen or shortages of such materials as oxygen, can cause the collapse of normal cyclical relationships and consequently, of the ecosystem itself.

Regulated and non-regulated accumulation. Some substances are taken up preferentially by living organisms. For example, potassium ions are actively imported across cell membranes in contact with the external environment whereas sodium ions are exported (to maintain cell excitability). Living organisms (except for certain primitive marine forms) contain more potassium in their body fluids and less sodium than in the external medium. Uptake of some ions in the process of active transport may be inadvertent, as when strontium ions (which have very similar chemical properties) accompany the incorporation of calcium ions. A great many ionic and other easily soluble substances which are found to be concentrated in living organisms may have been introduced via active transport across cell membranes. Other substances can be acquired by the animal consumer chain along with the ingested food. However substances which accumulate are acquired, they continue to build up to higher and higher concentrations unless they can be exported or excreted. Concentrations of substances which are difficult to export tend to be further magnified at each trophic level. Certain compounds of lead, mercury, and the chlorinated hydrocarbons are notorious examples of noxious substances which magnify until toxic levels are reached. Consequently, the upper trophic levels (the top carnivores, which include man in some circumstances) usually suffer the most damage from the introduction of substances which biomagnify.

Ecological Responses

Organism level. A convenient way to represent the relationship of an organism to its abiotic environment is presented in

Figure 7. Shelford's Law views the success or failure of an organism as controlled by the deficiencies and/or excesses of critical environmental variables (e.g. temperature, heavy metal salts). Although this concept does not take into consideration the interaction between variables, it does provide a spring board for discussion of the possibilities of interaction. As an example of this type of interaction, it has been shown with the lobster, *Homarus americanus*, that a shift away from the optimum range for temperature reduces or narrows the tolerance limits for both dissolved oxygen and salinity (McLeese, 1956). Presumably this holds true for many other variables and other organisms, but it has not been proven to fit all cases. The relationship between hardness and heavy metal toxicity is a case in point. The concept of an optimum hardness would be an interesting one to explore.

The organism, however, is an active participant in the ecosystem; it does not merely accept changes in the abiotic environment, it attempts to adapt to them. An organism has several possible options for adaptation. If the change is within tolerance limits, physiological adjustment usually begins immediately and may result in a shift in tolerance range in a matter of days or weeks (under controlled laboratory conditions the term acclimation is used to express this shift). Behavioral responses (typically escape reactions) may also be initiated at once. In addition, organisms have the capacity to resist short lived changes in abiotic factors, even those which surpass incipient tolerance limits. Thus, for example, lethal consequences of a three or four hour depression of dissolved oxygen levels to near zero in a pond during the night may be resisted by some kinds of aquatic organisms although they could not possibly survive under such conditions for very long.

If a change in an abiotic variable occurs over a relatively long period of time, approaching the life span or generation time of an organism, the organism may respond with phenotypic adjustments. These are adjustments which depend on conditioning in parent organisms or in early developmental (immature) stages (e.g. stunted growth when faced with chronic nutrient shortages). If the change is extremely long lived relative to generation time, options for genetic adaptation may be open to the species population.

It is useful to categorize organisms according to whether they have relatively broad (eurytopic) or narrow (stenotopic) tolerance ranges to a variety of abiotic factors. This categorization can also be made in terms of specific factors (e.g. stenothermal, euryhaline). The eurytopic organism is a generalist; its response to changing abiotic factors is typically physiological. Ubiquitous (cosmopolitan) forms found in relatively harsh environments tend to have these characteristics. Competition of eurytopic organisms with organisms well adapted to a specific environment rarely favors the eurytopic species; population densities of eurytopic

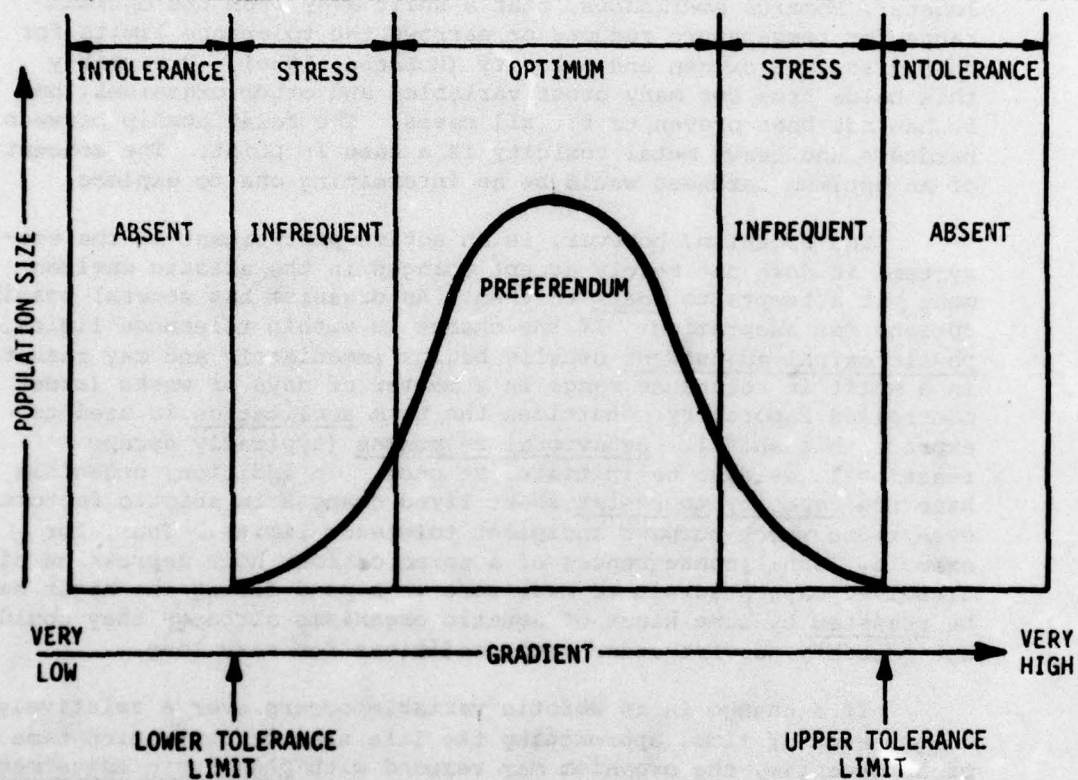


Figure 7. Illustration of the concepts in Shelford's Law of Tolerance.

organisms tend to be maximized under less than optimum abiotic conditions. The stenotopic organism, on the other hand, is a tough competitor given optimum abiotic conditions; its response to changing abiotic variables is typically genetic; gradual changes over very long periods of time (relative to generation time) favor this type of organism, whereas rapid changes may preclude its survival. Distribution of stenotopic organisms tends to be local or restricted to specific types of ideal environments. While these designations are primarily conceptual, there are organisms in the biosphere which fit into one or the other category very well.

Population level. Population responses are typically expressed in rates of changes in numbers. For example, a surplus of birth over death rates results in population growth. Environmental resistance (tolerance limits, intra and inter specific competition) imposes restraint on growth so that it is ultimately logistic (S-shaped) rather than exponential (J-shaped), as it may appear to be under initial or pioneer conditions. Population equilibrium is reached when the number of individuals is no longer changing appreciably. The concept of niche (i.e. living space) is useful in considering competition for resources or space. When intra specific competition exerts a restraint on growth which is greater than or equal to the restraint exerted by inter specific competition, niches of the species involved are said to be separated. By definition there can be no equilibrium while the niche occupied by one species overlaps that of another. One of the species must be removed from the overlap before dynamic equilibrium is reestablished. The outcome may hinge on inherent superior qualities of one of the competing species (qualities better suited to the particular niche) or simply numerical superiority (the species "first with the most"). Some populations appear to maintain competitive vigor only when they are in the exponential growth stage. Once the carrying capacity of the environment is reached and the growth rate levels off, the colony comes under stress and becomes vulnerable to competition from species which are now relatively more vigorous. These events are most typical of very small bodied organisms with very short generation times (e.g. bacteria, phytoplankton).

Community level. One characteristic that ecological communities have in common is dominance. The dominant species or groups receive the full impact of the environment (a role for which they are best suited) and alter it to suit their needs, thereby providing niches for associate or subordinate species. On land and in well lighted waters the dominant organisms are specific plants. In dimly lit waters, the dominants are animals. In early stages of ecological succession the dominants tend to be eurytopic species; the barren ground pioneer stage "lichens" are good examples.

Lichens alter the substrate, making conditions optimal for more stenotopic, but fiercely competitive, species. Sere replaces sere, as conditions reflect the optima for a succession of increasingly stenotopic forms. As successional development approaches maturity, niches become more finely divided and competitive interaction becomes less fierce until the community is so tightly interwoven that it completely resists further invasion. At this point the ecosystem may be essentially biologically controlled, as are many tropical ecosystems. Biological control means that catastrophic events (fire, floods, epidemic diseases, pest plagues, etc.) have minimal impact. The system is self regulating so that the effect of such occurrences are dampened (fire resistant growth, natural predator and parasite control of pests, etc.). Biological control exists to some degree in mature temperate communities, but the necessity of dealing with seasonal fluctuations means that a considerable degree of physical control is retained. Species diversity is a useful index of the relative degree of physical and biological control. Communities with the highest species diversity (number of varieties) usually have the greatest biological control. Near monocultures, such as are represented by agricultural crops, are notoriously lacking in biological control; plant diseases, parasites, and other pests are constant threats.

Biological control is only marginally possible in the aquatic environment. Life in a pond or stream are so dominated by fluctuations in physical parameters that community development is essentially arrested. Emphasis is on high rate of increase and short generation times. Primary producers are small bodied (single celled plants) with large surface to volume ratios. All of this is comparable to the early stages of successional development on land. In a physically controlled environment successional development towards stability and biological control tends to progress further if the fluctuations on physical parameters are predictable. For example, if a lake overturns regularly once or twice a year, its fauna and flora are usually more diverse than a lake which seldom overturns. Environments subject to waste effluents are usually good examples of unpredictable environments (especially where discharges are discontinuous or discharge quality fluctuates). Unpredictably stressed environments select for eurytropy, very high rates of natural increase and lack of niche specialization. In the unpredictable environment competitive interaction is a sporadic event. Populations are usually recovering from, or undergoing renewed physiological stress. When competition does occur it is usually counterproductive, selecting for a victorious species of the moment which, however, has an uncertain future. Short term diversity is very low, but the attractiveness of unexploited resources, made available by the severe stresses which have impaired habitation by the preceeding species, makes a chain or progression of opportunistic species likely. A polluted stream,

for example, may have a considerable variety of diversity of living forms over the length of its course and long periods of time; at a single point in space or time, however, the variety of living forms present is usually low. Many of these same principles are strongly illustrated in the streams of the Eastern Massachusetts Metropolitan Area.

DETERMINATION OF EXISTING CONDITIONS

A search for existing data was conducted over a three month period to obtain as much information as possible on the physical, chemical and biological properties of the waterways of the Eastern Massachusetts Metropolitan Area. The effort to obtain data was focused on the central portion (Boston Harbor and its tributaries) because of the vital influence of this central area and the intensity with which it has been surveyed. Parties, both public and private, too numerous to mention here, were contacted. Files and libraries of public agencies, such as the Massachusetts Department of Natural Resources, Division of Water Pollution Control; the New England River Basins Commission; and the United States Environmental Protection Agency, Region I, were carefully inspected.

The status of existing information is first presented in the form of an annotated bibliography. Following this review, selected data, taken from the literature, are used to describe existing conditions according to appropriate physical, chemical, and biological categories. Comments are included, indicating where substantial data are lacking. A subsequent section contains recommendations concerning the need for certain additional studies to provide a more complete base line from which to predict the environmental impacts of alternative wastewater management concepts.

EXISTING INFORMATION -- ANNOTATED BIBLIOGRAPHY

This bibliography includes only those reports and documents which contain information of a physical, chemical or biological nature about the estuaries and tributaries along the eastern Massachusetts coast from the Towns of Scituate to Gloucester, Massachusetts. Particular emphasis has been placed on those studies dealing with the monitoring of water and bottom sediment pollution in the Boston Metropolitan area, including watersheds of Boston Harbor enclosed by Hull Peninsula, Great Brewster Island, and Winthrop Peninsula.

Recent government actions concerned with pollution abatement and improvement of environmental quality are reflected in the fact that nearly all the work cited here has been carried out since 1966. In that year some important amendments were made to the Federal Water Pollution Control Act. Pollution surveys took place in the summer of 1967, involving both State and Federal agencies. The surveys have continued on a smaller scale since 1967 to culminate in the 1970-72 water quality monitoring program conducted by the New England Aquarium. Besides government sponsored surveys, federal regulations have encouraged base line ecological investigations in connection with the submittal of environmental impact statements. Documents pertaining to such statements have been cited here, especially where they have been determined to contain a reasonable amount of original material.

An apparent hiatus exists between studies conducted in the late sixties and two unpublished reports by the Woods Hole Oceanographic Institution which took place in Boston Harbor during the late forties and early fifties. No important original work of the nature described above has come to light which deals with the time period 1954 to 1965. In any case, recent activity on behalf of environmental quality has probably already effected changes in the conditions in coastal streams and estuaries which would reverse or confound trends seen in older works.

PUBLISHED MATERIAL

This section of the bibliography contains material which appears in print and is permanently bound. Comments at the end of each annotation indicate the availability of copies. Studies sponsored by federal, state or municipal authorities and public utilities were generally intended for public viewing, but many may be out of print and must be sought in specialized libraries, such as those of the Environmental Protection Agency and the New England River Basins Commission (both located in Boston, Massachusetts), or they may be borrowed from the files of the agencies themselves. Articles published in books or journals may be obtained

as reprints free from the author (as long as the supply lasts), or the entire volume bought from the publisher or borrowed from a library.

Brackley, R. A., W. B. Fleck and W. R. Meyer. 1973.

Hydrology and Water Resources of the Neponset and Weymouth River Basins, Massachusetts. U.S. Dept. Interior, Geological Survey. Hydrological Investigations. Atlas HA-484.

The three sheets are intended to compliment Brackley, Fleck and Willey (1973). Data are presented in both graphical and cartographical form. Sheet 1 contains data on precipitation, ground water yield and the hydrologic budget. Sheet 2 presents stream flow characteristics (flood levels, high and low flow frequencies, duration, storage and diversions). Sheet 3 contains data on ground and surface water quality (pH, nitrates, hardness, iron, manganese, sulfate, and chlorides). Narrative summaries and explanations accompany some of the displays. Copies are available from Massachusetts Water Resources Commission.

Brackley, R. A., W. B. Fleck and R. E. Willey. 1973.

Hydrologic Data of the Neponset and Weymouth River Basins, Massachusetts. U.S. Dept. Interior, Geological Survey. Massachusetts Hydrological Data Report No. 14. 51 pp.

This is the latest in a series of basic hydrologic data reports for Massachusetts. Previous reports on localities in Massachusetts and New Hampshire are listed and described at the end of the Publication. This report provides data for the years 1965 through 1968 on seasonal stream discharge, plus chemical analyses of ground water (69 sample sites) and surface water (68 sample sites including 7 on the Neponset River). Data are presented on dissolved silica, iron, manganese, calcium, magnesium, sodium, potassium, bicarbonate, sulfates, chlorides, flourides, nitrates, dissolved solids, hardness, alkalinity, conductance, pH, color, turbidity and temperature. A few sites have complete data for almost every month. Copies are available from Massachusetts Water Resources Commission.

Camp, Dresser and McKee, Consulting Engineers. 1967.

Report on Improvements to the Boston Main Drainage System. Volumes I and II.

The report describes in detail existing conditions and proposed alternatives with regard to the management of wastewater. Standards of water quality to be achieved are given but no specific comparison is made with existing chemical or ecological conditions. Useful data contained in the report include water supply demands, sewage volumes, precipitation (from U. S. Weather Bureau Sources). and runoff. Copies are available for study but not for distribution.

Charles E. Maguire, Inc. 1973. Water Quality Improvement of the Boston Back Bay Fens. Prepared for the Commonwealth of Massachusetts, Division of Water Pollution Control. May, 1973.

This comprehensive study of sewer and surface discharge systems includes descriptions and chemical analyses of the water and benthal (sludge) deposit quality and quantity in Fens Pond. Graphical presentations of benthal deposits show bathymetry, sludge volumes, analysis for hexane solubles, B.O.D., C.O.D., volatile solids, total phosphorous and (Kjeldahl) nitrogen, and trace metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, vanadium and zinc). Water quality parameters discussed include coliform counts (total and fecal), total phosphorous and nitrogen, suspended solids, B.O.D., and dissolved oxygen. The original laboratory data sheets are reproduced in Appendix A. The content of the benthal deposits is typical of primary settled treatment plant sludge according to the report. The eutrophic condition prevailing in the pond is described in general. Algal and weed growth are cited but no specific mention of flora or fauna is included. The conclusion is that existing conditions are far below the most liberal acceptable standards. Half of the report is devoted to corrective measures. Copies are available for study but not for distribution.

Chesmore, A. P., D. J. Brown, and R. D. Anderson. 1972. A study of the Marine Resources of Lynn-Saugus Harbor. Commonwealth of Massachusetts Dept. of Natural Resources. Division of Marine Fisheries. Monograph Series No. 11. March, 1972. 38 pp.

This report is one of a series on local estuarine areas along the Massachusetts coast, all of which have approximately the same format. The contents include morphometry (cross-sections, submerged volume); hydrographic data (monthly temperature, salinity, pH, dissolved oxygen and carbon dioxide); monthly coliform counts; and pesticide concentrations in sediments, soft-shell clams (*Mya arenaria*) and winter flounder (*Pseudopleuronectes americanus*). Relative abundance of finfish species is determined from inshore seining and offshore trawling and gill netting. Common invertebrate species associated with the economically important *Mya* are listed. Lastly, an inventory of marine flora (macroalgae and vascular plants) is included. Copies are available on request.

Chesmore, A. P., D. J. Brown and R. O. Anderson. 1973. A study of the Marine Resources of Essex Bay. Commonwealth of Massachusetts Dept. of Natural Resources. Division of Marine Fisheries. Monograph Series No. 13. January, 1973. 38 pp.

For a description, see Chesmore et al., (1972). Copies are available on request.

Chesmore, A. P., D. J. Brown and B. Ketschke. 1973.
Investigations of the Effects of Electrical Power
 Generation on Marine Resources in Salem Harbor. Progress
 Report No. 6, January-March, 1973. Massachusetts Dept.
 of Natural Resources, Division of Marine Fisheries.

This is one of a series of quarterly reports which includes:
 continuous temperature recordings; weekly sampling for salinity,
 pH, carbon dioxide, dissolved oxygen, B.O.D., nitrites, nitrates,
 phosphates and chlorophyll *a*; analysis of soft-shell clams (*Mya*
arenaria) and lobsters (*Homarus americanus*) for copper content; a
 survey of benthic invertebrates (including determination of density
 and diversity with depth of seabottom); a phytoplankton and zoo-
 plankton inventory (including correlation of phytoplankton density
 with chlorophyll *a* concentration); a determination of relative
 abundance of dominant copepods; a finfish survey (including relative
 abundance, size-frequency, fishing effort determinations); and a
 lobster tagging study. Copies are available in limited quantity.

Chesmore, A. P., D. J. Brown, B. A. Ketschke and E. M. Sawin.
 1973. Investigations of the Effects of Electrical Power
 Generation on Marine Resources in Salem Harbor. Progress
 Report No. 7, April-June, 1973. Massachusetts Dept. of
 Natural Resources. Division of Marine Fisheries.

Identical in format and content to the citation immediately
 preceeding, except that no plankton studies are reported. Copies
 are available in limited quantity.

Chesmore, A. P., D. J. Brown, B. A. Ketschke and E. M. Sawin.
 1973. Investigations of the Effects of Electrical Power
 Generation on Marine Resources in Salem Harbor. Progress
 Report No. 8, July-September, 1973. Massachusetts Dept.
 of Natural Resources. Division of Marine Fisheries.

Similar in format and content to previous citations of the
 same title except sections have been added on morphometry, surface,
 current patterns and monthly wind direction for 1973, and occurrence
 and abundance of fish eggs and larvae. The section on benthos has
 been considerably expanded to include: quarterly summaries of mean
 number individuals, mean weight and percent composition for each
 species collected for the past four quarters, quarterly summaries
 of order of abundance by station, and quarterly summaries of faunal
 overlap. Copies are available in limited quantity.

Chesmore, A. P., S. A. Testaverde and F. P. Richards. 1971.
A study of the Marine Resources of Dorchester Bay.
 Commonwealth of Massachusetts Dept. of Natural Resources.
 Division of Marine Fisheries. Monograph Series No. 10.
 March, 1971. 41 pp.

For a description, see Chesmore *et al.*, (1972). Copies are

available on request.

Cochrane, J. J., C. J. Gregory and G. L. Aronson. 1970. Water Resources Potential of an Urban Estuary (Saugus River, Pines River and Lynn Harbor Complex). Northeastern University, Boston, Massachusetts. June, 1970. 83 pp.

This report identifies a marine algal species, *Ulva latissima*, as having the most prolific growth response to eutrophic conditions existing in the area described. Laboratory studies were made to determine the response of this algal species to nitrogen and phosphorous in various concentrations and relative proportions. Laboratory studies were also made on the rate of release of the two nutrients to the water column. A bottom sampling program was undertaken during the summer of 1969 to determine nutrient levels in the Saugus River. Benthic results reported include: total and extracted orthophosphates ($PO_4^{=}$), total Kjeldahl nitrogen, nitrates (NO_3^-), and volatile solids. Average orthophosphate and nitrate concentrations are given for water samples taken throughout the study area. The water data are displayed in map contour as well as tabular form. Copies are available in limited quantity.

Commonwealth of Massachusetts. 1970. Coldwater Fisheries Investigations: Survey of Streams. August 1, 1969 to July 31, 1970. Dept. of Natural Resources. Division of Fisheries and Game.

Rotenone, electric shocking, gill nets and a seine were used to collect 4,213 finfish at 28 sampling sites along the Charles River watershed. The fish collected represented 29 species. Tables give length and weight data by stations as well as by species. Of fourteen species aged, chain pickerel appeared to exhibit a growth rate in the Charles which was higher than the state average. Other species grew slower than the average. Another table presents morphometric data, water temperature, dissolved oxygen and pH recorded at each collection site, as well as a brief description of stream conditions with regard to general pollution. Total alkalinity, hardness, heavy metals (combined) and ferrous iron content are given for five of the stations (identified on a map). Copies are available in limited quantity.

Commonwealth of Massachusetts. 1972. Fifty-Third Annual Report: Metropolitan District Commission, Sewerage Division. Fiscal Year Ending June 30, 1972. 43 pp.

Included in the summary of operation data for the Deer Island and Nut Island treatment plants are the quality and quantity of effluent and sludge discharged into Boston Harbor. Suspended solids, oil and grease, settleable solids, 5-day B.O.D., bacterial concentration, residual chlorine, alkalinity and pH values are

stated. Copies available on request.

Commonwealth of Massachusetts. 1972. Report of Routine Chemical and Physical Analyses of Public Water Supplies in Massachusetts. Dept. of Public Health, Division of Environmental Health. Boston, Mass.

This report is compiled and published annually from analyses performed at the Department's Lawrence Experiment Station. It contains tables of data for the reporting year on: pH, iron, magnesium, ammonia as nitrogen, nitrate as nitrogen, chlorides, sodium, alkalinity, color and hardness for all public water supplies in the state. Analyses are performed on each site from one to three times during the year. The sites are grouped by town and are listed alphabetically. The report is divided into two parts, the first dealing with ground (well) water supplies; the second with surface supplies, including portions of some streams which are used as a public water supply. Copies are available in limited quantity.

Commonwealth of Massachusetts. 1972. Harbor Crossing. Dept. of Public Works, Boston Transportation Planning Review. Draft Environmental Impact Statement. 341 pp.

This report is rather limited in scope but does contain a brief description of sediments in Boston Inner Harbor and Fort Point Channel (corridors proposed for a third tunnel from Downtown to East Boston). The results of chemical analyses of two sediment samples, one from Fort Point Channel, one from Boston Inner Harbor show that the Channel has substantially heavier concentrations of volatile solids, C.O.D., total Kjeldahl nitrogen, oil and grease, mercury, lead, and zinc (the constituents analysed). Copies available for study but not for distribution.

Commonwealth of Massachusetts. 1972. Boston Harbor Islands Comprehension Plan. Dept. of Natural Resources. Metropolitan Area Planning Council. 167 pp.

The chief value of this study to the present review lies in the contents of appendices III and IV which contain information on flora and fauna of the area, including acreage of salt marsh and productive clam flats. Copies available on request.

Commonwealth of Massachusetts. 1973. Ipswich River Study 1973: Part A. Water Quality Survey Data. Massachusetts Water Resources Commission, Division of Water Pollution Control, Water Quality Management Section. Westboro, Massachusetts. 54 pp.

This report represents a continuation of a previous survey of the same river in 1968 (Tennant et al., 1970). Samples were collected from 15 locations four times in each of six 24-hour periods during 4-8 June and 13-17 August, 1973. The report lists data on dissolved

oxygen, temperature, B.O.D., ammonia, nitrates, total phosphorous, alkalinity, pH, suspended solids, coliform bacteria (total only), chlorophyll a, and stream flow. Most of the data are summarized in graphic displays. Quantitative data on planktonic organisms are given in general categories only (e.g., diatoms, bluegreens, rotifers, crustacea). Results of photosynthetic activity determinations by the light and dark method at three river locations are given. Copies are available on request.

Commonwealth of Massachusetts. 1973. Neponset River Study 1973: Part A. Data Record on Water Quality. Massachusetts Water Resources Commission, Division of Water Pollution Control, Water Quality Management Section. Westboro, Mass. 59 pp.

Data included in this report were collected during 9-13 July and 13-17 August, 1973. Water samples were collected at 15 locations on the main branch of the Neponset, one location on the east branch, and one on Hawes Brook. The methodology used and parameters listed are the same as described in the preceding report except that four light and dark bottle locations were used rather than three. Copies are available on request.

Commonwealth of Massachusetts. 1973. North River Study 1971: Data Record on Water Quality. Massachusetts Water Resources Commission, Division of Water Pollution Control, Water Quality Management Section. Westboro, Mass. 61 pp.

This report lists data on: dissolved oxygen, temperature, B.O.D., suspended solids, alkalinity, coliform bacteria, color, turbidity, total phosphorous, nitrates, organic nitrogen, ammonia, chlorides, and specific conductance for 21 sampling stations on the North River and its tributary streams. Much of these data are graphically displayed. The main survey was conducted during four 24-hour periods from 22 June to 1 July, 1971. Results are given of a special survey to determine trace metal content (cadmium, chromium, copper, lead, mercury, and zinc) from both water and sediment samples. Results of special studies to determine photosynthetic activity by the light and dark bottle method (three replicates at five locations) and to determine the influence of dams on dissolved oxygen concentration (two replicates at five locations) are also reported. The quantity of chlorophyll a, amorphous matter, and debris lying on the river bottom is tabulated along with remarks on the bottom life. Stream flow data and an analysis of wastewater discharges from four sources (in terms of B.O.D. solids, pH, turbidity, chlorides, phosphorous, and nitrogen) are presented at the end of the report. A two page description is given of the basin drainage including conditions regarding pollution. Copies of the report are available on request.

Commonwealth of Massachusetts. 1974. Mystic River 1973.

Part A. Water Quality Survey Data. Massachusetts Water Resources Commission, Division of Water Pollution Control, Water Quality Management Section. Westboro, Mass.

This report represents a continuation of a previous survey in 1967 (Tennant and Jobin, 1970). Samples were collected from 18 locations; eight of these were along the course of the Aberjona River, one each at the outlets of Upper and Lower Mystic Lake, and three on the Mystic River mainstem. The remaining five stations were located on tributaries: Hall's Mill and Alewife Brooks, and the Malden River estuary. The collecting periods were 12-15 June and 7-9 August, 1973. The data are presented in standardized format as described for the Commonwealth of Massachusetts, Ipswich River Study 1973. Copies of this report are available on request.

Commonwealth of Massachusetts. 1974. Charles River Study 1973. Part A. Water Quality Survey Data. Massachusetts Water Resources Commission, Division of Water Pollution Control, Water Quality Management Section. Westboro, Mass.

Copies of this report, which is similar to other 1973 studies by the Division, will be available on request in mid-1974.

Duesik, D. and T. Najarian. 1971. "Water Quality Improvement in Boston Harbor" Chapter 5 in: Duesik and Soifert (eds): Power Pollution and Public Policy. Massachusetts Institute of Technology Press. Cambridge, Mass. pp 242-281.

The authors present evidence, gathered from surveys by various government agencies, that sludge is a primary contributing factor to the presence of high density population of bacteria in Boston Harbor waters. Potentially troublesome constituents other than bacteria (such as heavy metals) are not considered in this report. The authors suggest that harbor dumping of sludge be avoided and that drying and storage on land may be feasible. The complete publication is available for \$12.00.

Ferullo, A. F., P. G. Moleux and W. R. Jobin. 1971. Charles River Study 1967. Part A: Data Record on Water Quality. Part B: List of Wastewater Discharges. Massachusetts Water Resources Commission, Division of Water Pollution Control. 42 pp.

Part A. Contains results of a survey conducted on 22, 24 August and 5, 7 and 26 September covering 70 miles of the river from its source at Hopkinton, Massachusetts to Watertown Dam. Seventeen stations were sampled for temperature, dissolved oxygen, five day B.O.D., pH, turbidity, color, alkalinity, suspended solids, nitrates,

organic nitrogen, ammonia, nitrites, total and orthophosphate, and coliform counts. Samples were taken four times each day, at four-hour intervals. Two samples from each station, taken on separate days, were also examined for microfauna and flora. Results are reported in standard units per cc. in a table. Detailed classification is lacking except for two genera of bacteria (*Sphaerotilus* and *Detinophrys*). There is also a brief analysis of bottom sediments from most of the stations, which consists of a short physical description and the proportion of volatile solids, organic and inorganic debris. Comments are made on the kinds of bottom dwelling animals present (if any). Copies are available on request.

Part B. Lists fifteen major pollution sources and gives data on the effluent constituents as sampled in February and March, 1968. Constituents reported vary with the pollution source but generally include temperature, volumes, C.O.D., B.O.D., suspended solids, pH, alkalinity, phosphates and, occasionally, nitrogen and hexane solubles (oil and grease). No mention is made of trace metals.

Part C is cited as: Jobin and Ferullo (1971).

Gilbert, T., G. C. McLeod, R. Moehl, K. V. Ladd, A. Clay and A. Baker. 1972. Trace Metal Analysis of Boston Harbor Water and Sediments. Boston Harbor Water Quality Monitoring Program. Volume II. New England Aquarium Research Dept. 98 pp.

Approximately 180 sediment cores were analyzed for zinc, lead, copper, cadmium, cobalt, chromium, vanadium, molybdenum, nickel and mercury by atomic absorption spectrometry, and for organic content. High levels of metal concentrations and organic matter were associated with sewage outfalls and with Boston Inner Harbor. Gas chromatographic analysis identified a substantial portion of the organic matter were associated with sewage outfalls and with Boston Inner Harbor. Gas chromatographic analysis identified a substantial portion of the organic matter as petrochemical. The complexities of local hydrographic conditions somewhat confounded precise interpretation of data. The importance of bottom sediments as a repository of heavy metals is discussed, as is the role of benthic organisms in re-introducing metallic elements into the aquatic zone. Future study plans include determination of the proportion of each metal species bound as sulfide and a laboratory examination of uptake of metallic elements by natural sea water. Availability of copies is limited. This is one of two major surveys of trace metal content in Boston Harbor.

Hites, R. A. 1973. "Phthalates in the Charles and the Merrimack Rivers". Environmental Health Perspectives. 13:17-21.

Phthalates are organic compounds used in the plastics industry.

In this report the fate of this plasticizer is determined by following its path downstream in the Charles River from river mile 7 to mile 1. Dilution by runoff and severe vertical stratification in the lower Basin are documented. Reprints are available on request.

Hites, R. A. and K. Biemann. 1972. "Water Pollution: Organic Compounds in the Charles River, Boston." Science. 178: 158-160.

The analytical capabilities of computerized gas chromatography, mass spectrometry and high pressure liquid chromatography for the precise identification of specific organic compounds in river water are successfully demonstrated. An inventory of such substances, found in Charles River water samples taken in fall, 1971, is provided. The data indicate that automobile exhaust condensate contributes to pollution in this river. A close correlation was found between total concentration of naphthalenes and storm water runoff. Reprints are available on request.

Hydroscience, Inc. 1971. Final Report: Development of Water Quality Model of Boston Harbor. Massachusetts Water Resources Commission, Boston, Mass. 173 pp, four appendices.

This report presents mathematical models to evaluate the effects of wastewater management alternatives on: coliform count, B.O.D., dissolved oxygen, digested sludge solids, nitrogen and phytoplankton populations. Results of the predictions and verifications are presented on maps of Boston Harbor. Salinity distribution is used to verify predictions of freshwater advection and tidal dispersion. Principle sources of B.O.D. and coliforms are described and shown on a map. It is estimated that a 96 per-cent reduction in coliforms discharged from projected sources will be required by the year 2020. Construction of the steady state model is based on formulating a mass balance equation for each of a series of 76 interconnected segments. Material entering and leaving each segment due to non-tidal (advective) flow, tidal mixing (dispersion) and sources and sinks within the segment is considered. Mathematical expression and computer program listing (Fortran) of the steady state and study solids models are presented in the Appendices. Availability of copies is limited.

Hydroscience, Inc. 1973. Development of Hydrodynamic and Time Variable Water Quality Models of Boston Harbor.

The models presented in this report take into consideration the fact that wastewater discharges are discontinuous and therefore never in a steady state condition. The first model takes into consideration hydrodynamic forces related to tidal motion (including friction forces and Coriolis acceleration) but not wind effects, density gradients or atmospheric pressure differences. No provision

is made for inundation or uncovering of tidal flats or freshwater flow. Input consists of mean water depths, friction coefficients, tidal stage, velocity in 236 water segments verified from U. S. Government current meters and charts.

The second model was constructed to generate pollutant concentrations due to time variable discharges of sewage wastes. The pollutant concentrations are assumed to be conservative or to follow first order kinetics. Coupled together, the two models were used to estimate coliform concentrations. It was concluded that the model's prediction capabilities are acceptable for coliform discharges located along the coastline but not for those located near the ocean boundary between Hull and Deer Island. Some suggested uses for the model are: evaluation of the effects of relocating discharges, separating sewers, installing holding tanks, and repairing tide gates. Availability of copies is limited.

Iwanowicz, H. B., R. D. Anderson and B. A. Ketschke. 1973. A Study of the Marine Resources of Hingham Bay. Commonwealth of Massachusetts Dept. of Natural Resources, Division of Marine Fisheries. Monograph Series No. 14. March, 1973.

For a description, see Chesmore et al., (1972). Copies are available on request.

Jerome, W. C., Jr., A. P. Chesmore and C. O. Anderson, Jr. 1966. A Study of the Marine Resources of Quincy Bay. Commonwealth of Massachusetts. Dept. of Natural Resources. Division of Marine Fisheries. Monograph Series No. 2. 62 pp.

For a description, see Chesmore et al., (1972). Copies are available on request.

Jerome, W. C., Jr., A. P. Chesmore and C. O. Anderson, Jr. 1967. A Study of the Marine Resources of Beverly-Salem Harbor. Commonwealth of Massachusetts. Dept. of Natural Resources. Division of Marine Fisheries. Monograph Series No. 5. December, 1967. 74 pp.

For a description, see Chesmore et al., (1972). This publication is currently out of stock.

Jerome, W. C., Jr., A. P. Chesmore and C. O. Anderson, Jr. 1969. A Study of the Marine Resources of the Annisquam River-Gloucester Harbor Coastal System. Commonwealth of Massachusetts. Dept. of Natural Resources. Division of Marine Fisheries. Monograph Series No. 8. December, 1969. 62 pp.

For a description, see Chesmore et al., (1972). Copies are

available on request.

Jobin, W. R. and A. F. Ferullo. 1971. Report on the Charles River: A Study of Water Pollution. Massachusetts Water Resources Commission. Division of Water Pollution Control.

This report constitutes the "discussion" of the results shown in Ferullo et al., (1971). Water quality is discussed in terms of bacterial quality, dissolved oxygen, algae, salt water intrusion and bottom deposits. River quality improvement projects are discussed. Future conditions in the river are projected for years 1980 and 2000. In terms of B.O.D. loadings, the more serious problems develop in the river when temperatures are warm. Copies are available on request.

Karpen, J. 1973. Spring runoff and nutrient seawater density correlations in the Massachusetts Bay. Part II. Dissolved nutrient-seawater density correlations and the circulation in Boston Harbor and vicinity. Massachusetts Institute of Technology Sea Grant Project Office, Report No. MITSG 74-9. 108 pp.

Circulation between Boston Harbor and adjacent portions of Massachusetts Bay was investigated as a tidal exchange problem. Sewage effluent from the Deer Island treatment plant was used to represent the movement of harbor water into Massachusetts Bay. A mathematical model, based on a "jet and sink flow" principle, was developed to describe dispersion of the effluent. Five cruises, undertaken from August, 1972, to May, 1973, and involving 100 sampling stations, verified the correlation between dissolved nutrients (nitrates, nitrites and orthophosphate) concentrations and small differences in sea water density (σ_t). Movements of Deer Island effluent seaward were characterized as "blob" like. Data on monthly average river flows are given for the Charles, Mystic-Chelsea, and Neponset Rivers (December, 1972, through May, 1973). Data on monthly (August, 1972, through May, 1973) analyses of effluent chemical concentrations (chlorides, nitrates, orthophosphate and nitrites) are also presented.

Landrum and Brown, Inc. 1971. "Impact of Airport Improvements and Operations on Water Quality". Chapter IV in Boston-Logan International Airport Environmental Impact Study. Massachusetts Port Authority, Boston, Mass. 44 pp.

Current meters, tide meters and drogues were used to investigate hydrographic conditions in the vicinity of the airport. Results of the field measurements and a computerized predictive model showed that water quality was directly related to discharges from the City of Boston Sewer located at the extension of Coleridge

and Moore Streets. Water quality met specifications for the highest state classification (SA) as long as the sewer did not overflow. Counts on the order of 6,000 coliform organisms per 100 ml. were measured at the sewer mouth after rainfall whereas counts of less than 10 were observed in day weather. There was little evidence of pollution in the sediments during April, 1971. Clamworms, soft-shell clams and other polychaete species were observed in the mud. This study is rather limited in scope and therefore not especially important. Copies are available for study but not for distribution.

Lord, S. M., R. C. McAnespie and P. A. Dore. 1973. Boston Harbor Pollution Survey - 1972. Part A: Data Record of Water Quality and Wastewater Discharges. Massachusetts Water Resources Comm. Div. of Water Pollution Control. 142 pp.

This report contains the results of analyses of water and sediment samples collected at 167 sites in Boston Harbor, including the estuarine portions of tributaries. Samples were collected during summer and early fall of 1972 by U. S. Coast Guard Reserve Units. At most sites water samples were collected several times during the study period. Water samples were analyzed for temperature, pH, B.O.D., alkalinity, dissolved oxygen, chlorides, suspended solids, total phosphorous, total and fecal coliforms, color, turbidity, total Kjeldahl nitrogen, ammonia, and nitrate as nitrogen (nitrate values appear to have been insensitively determined). Atomic absorption analyses were performed on sediment samples from most of the sites for: arsenic, cadmium, chromium, copper, lead, mercury, nickel, zinc. Proportion of volatile solids was also determined but not organic nitrogen content. This study might be considered supplemental to the New England Aquarium Water Quality Monitoring Program which was much broader in scope, but utilized fewer stations. Copies are available in limited quantity.

Lord, S. M., R. C. McAnespie, D. E. Costello and W. R. Jobin. 1970. Boston Harbor Pollution Survey - 1968. Commonwealth of Massachusetts. Dept. of Natural Resources. Division of Water Pollution Control. 80 pp.

Sources of pollution discharging into Boston Harbor and estuaries of its tributaries were catalogued. There were 405 sources specified. Data are presented on methylene blue active substances (detergents), five-day B.O.D., pH, alkalinity, suspended solids, oil and grease, and orthophosphate for 49 sampling stations. Many gaps exist in the data. Parameters for which there are data on most sites are: B.O.D., pH, alkalinity and suspended solids. Copies are available for study but not for distribution.

Marine Environmental Services. 1970. Ecological Field Survey in the Mystic River, September 1970. Report prepared for Stone and Webster Engineering Corporation. Boston, Mass. 24 pp.

This is the first report of a series of surveys carried out in connection with a proposal for the addition of a electric generating unit (No. 7) to Boston Edison's Mystic Station at Everett, Mass. The initial survey included: water sampling at six cross-river transects between the Tobin Bridge and Amelia Earhart Dam (temperature, salinity, pH, dissolved oxygen, ammonia, nitrite, nitrate, total phosphate, particulate phosphorous, turbidity, total phosphorous, and coliform bacteria), bottom sampling for benthic invertebrates, and trawling for finfish. The survey was conducted during 7 and 8 September. Biomass and dominant species present are reported for each of the bottom samples along with a short description of the sediment. Size, age, sex and stomach contents are reported for each of the finfish. Only two fish species were represented in the catch; of the two species, only winter flounder were collected in every tow. Copies are not available for general distribution.

Marine Environmental Services. 1972. Ecological Field Survey in the Mystic River, June 1972. Report prepared for Stone and Webster Engineering Corporation. Boston, Mass. 24 pp.

This report expands the scope of the previous report (Marine Environmental Services, 1970) to include chlorophyll a determinations and a phytoplankton and zooplankton survey (phytoplankton: cell density, abundance of dominant species, and relative abundance of all species; zooplankton: species density, diurnal changes in relative abundance). An enhanced trawling effort resulted in the capture of 299 finfish representing ten species. The study was conducted from 15 through 18 June 1972. Copies are not available for general distribution.

Marine Environmental Services. 1973. Ecological Field Survey in the Mystic River, August 1972. Report prepared for Stone and Webster Engineering Corporation. Boston, Mass. 27 pp.

This report expands the scope of the previous report (Marine Environmental Services, 1972) to include atomic adsorption analysis of heavy metal content in shellfish and sediments (cadmium, copper, chromium, lead, nickel and zinc). Triplicate samples of 12 clams and 86 mussels were analyzed. Highest concentration levels in the shellfish were for zinc and copper, respectively. Together with the two preceding reports, the series provides the most comprehensive ecological information available on the Mystic River estuary. Copies are not available

for general distribution.

Mencher, E., R. A. Copeland and H. Payson, Jr. 1968.
 Surficial Sediments of Boston Harbor, Massachusetts.
Journal of Sedimentary Petrology. 38(1):76-86

Analyses of composition (sand, gravel, salt, clay, etc.), grainsize distribution, and percent organic carbon were performed on 152 grab samples. Sediments ranged from very poorly sorted black muds to sandy mud. Most recent sediments were found to be poorly sorted black muds, rich in organic matter. The detrital fraction appeared to be derived from erosion of the Harbor Islands. The coarser organic fraction appeared to originate as windblown coke and coal particles. Comparison of the distribution of finely divided organic fraction appeared to originate as windblown coke and coal particles. Comparison of the distribution of finely divided organic matter in the mud, with that predicted from the location of outfalls, demonstrated that sewage is the source of the bulk of the organic matter in the sediments. Organic carbon content ranged from 1 to 30 percent with 98 percent of the samples falling between 1 and 15 percent. Tidal movements are portrayed and described. Availability of reprints has not been determined. The journal is available in most college science libraries.

New England Aquarium Research Dept. 1973. Water Quality Measurements of Boston Harbor. Boston Harbor Water Quality Monitoring Program. Volume I. Boston, Mass. 55 pp.

This is the first of three volumes reporting the results of an investigation sponsored by the Massachusetts Department of Natural Resources to expand and continue previous surveys in Boston Harbor (1967 to 1969) conducted by federal and state pollution monitoring authorities. Volume I presents the water quality data collected and describes the computer storage and retrieval system developed to handle the collected data. Thirteen sampling stations were established in the Inner and Outer Harbor. Samples of surface and bottom water were collected on a weekly basis at each station from June to December 1970 and July 1971 to June 1972. These samples were analyzed for: total coliforms, temperature, salinity, pH, tidal stage, total phosphorous, orthophosphate, ammonia, nitrate, dissolved oxygen and chlorophyll a. A more intensive sampling program was conducted at one site on 16 to 17 February, and on 24 to 25 April, 1972 to assess diurnal and tidal influences on the parameters cited prior to and during a spring bloom. Also, a study of time variable relationships of the cited parameters was made at three stations on 12 July 1972. The two short period studies demonstrated an important tidal influence on water constituents. Among the important contributions made by this investigation are: 1) emphasis on the value of considering such variables as tides and perturbations in fresh water inflow in a pollution monitoring program, 2) initiation

of chlorophyll a measurements in Boston Harbor, and 3) fostering appreciation of the quantity and concentration of data collection needed to properly describe the chemistry of an estuary system.

Appendix I shows the (direct) relationship between coliform levels and heavy precipitation, and also describes the phytoplankton (diatom) community of Boston Harbor. Appendix II describes the buoy system used to continuously record temperature, salinity, depth and time in President Roads near Deer Island sewage treatment plant (MDC). Copies are available on request at \$4.50 each.

Rice, H. V. and W. R. Patterson. 1973. Experimental Analysis of Boston Harbor Water Quality Data with the Model Bio-Dyn III. Boston Harbor Water Quality Monitoring Program. Volume III. New England Aquarium Research Dept. Boston, Mass. 55 pp.

A time-variable simulation model was used to identify patterns and to project trends in a few water quality parameters (chlorophyll a, inorganic nitrogen, orthophosphate and dissolved oxygen). Input data was taken from Boston Harbor from 1970 to 1972 (see Vol. 1). The ability to simulate environmental responses is limited to prediction of nutrient and energy fluctuations. Computer generated graphic displays are included in the report. The model does not provide any insight into waste assimilation capacity or ability to assimilate organic material or "exotic" components (other than trace metals). Meteorological factors (e.g. light, temperature and precipitation) were concluded to be major influences on the parameters considered. A distinct gradient of inorganic nitrogen content, decreasing towards the Outer Harbor was detected. Conditions of eutrophication were identified with nitrogen (as a limiting factor). Nitrogen input from land runoff was found to be greater than input from sewage. The input of energy into the harbor ecosystem from sewage sources approximately equaled the energy fixed by phytoplankton (primary productivity). Recommendations for further uses of the model include: characterization of the waste flows of Boston Harbor and associated bays, and prediction of summer health hazards, and petrochemical and chlorinated hydrocarbon accumulations. Parameters must be selected carefully since the model, as presently constructed, has limited input capacity. Copies are available in limited quantity.

Rowe, G. T., P. T. Polloni, and J. I. Rowe. 1972. Benthic community parameters in the lower Mystic River. Int. Revue ges. Hydrobiol. 57(4):573-584

Data from benthic surveys performed by Marine Environmental Services for Boston Edison Company were used to determine numerical abundance, biomass, diversity and faunal composition. The Mystic River below Amelia Earhart Dam is characterized as a highly polluted and stressed environment. Sediments are anoxic, containing up to 34 percent organic matter. Oxygen concentrations in the bottom

water are low as is the diversity of benthic macrofauna. Species commonly considered pollution indicators are abundant. The depauperate conditions appeared to have been ameliorated somewhat in the immediate vicinity of thermal effluent from the Everett, Massachusetts electric-power generating station. Possible theoretical relationships between pollution stress and diversity, relative to latitudinal selection processes are discussed. Availability of reprints has not been determined. The journal is available in science libraries of major universities.

Runas, C. E. and L. A. Resi. 1968. Chemical and Physical Aspects of Water Quality: Charles River and Boston Harbor, Massachusetts. U.S. Dept. Interior. Federal Water Pollution Control Admin. Technical Advisory and Investigations Branch. Cincinnati, Ohio.

In addition to eighteen stations in Boston Harbor and seventeen on the Charles River, this study included two stations each on Neponset and Chelsea Rivers and one each on the Mystic, Malden, Weymouth, Fore and Back, and Weir Rivers. Samples were analyzed for temperature, dissolved oxygen, pH, turbidity, color, nitrates, organic nitrogen, ammonia, total and soluble phosphorus, and total and fecal coliform bacteria. In addition, river samples were analyzed for alkalinity, 2-day and 5-day B.O.D., and suspended solids; the harbor samples received additional analyses for salinity. Results are displayed graphically. Numerical results are tabulated in the appendix.

The report also includes an inventory of *Salmonella* species isolated from water samples and a study of growth and survival of four species of bacteria (*Aerobacter aerogenes*, *Escherichia coli*, *Salmonella typhi-murium* and *Streptococcus fecalis*) in sterile river water samples. Copies are available in limited quantity.

Sawyer, C. N. 1965. The sea lettuce problem in Boston Harbor. Water Poll. Contr. Fed. J. 37(8):1122-1133

Nuisance growths of sea lettuce, *Ulva lactuca*, are reported for three areas of Boston Harbor, in Winthrop, Squantum and Quincy Bays. Winthrop Bay was described as being highly contaminated by sewage discharges from an outfall of the Deer Island plant. Bacterial counts are given in two tables for 15 locations in Winthrop Bay. Concentrations of ammonia nitrogen and phosphate as phosphorus are given in tables for the same 15 locations. The sewage discharge was identified by dye tracer studies as the principal source of nutrients for extensive sea lettuce growth. Results of experiments on chemical control of this algal nuisance are given. The Journal is widely available (engineering libraries and Federation member institutions).

Smith, J. D., J. J. Harrington, B. F. Heiler and H. Radiloff.
1972. Combined Sewer Overflows to the Charles River Basin. A Preliminary Study. Process Research, Inc.
Cambridge, Mass.

Descriptions of sources and volumes of sewage overflows are given. Water quality data from storm runoffs occurring in November 1971 and (once) in March 1972 include C.O.D., B.O.D., pH, total nitrogen and phosphorous, solids, and coliform counts. Also described are the results of a water quality survey program conducted during the summer of 1971 (C.O.D., coliforms, dissolved oxygen, temperature, ammonia, nitrates, phosphates and total phosphorous, pH, chlorides, conductivity and colot). Samples were collected from twenty stations between Watertown and Charles River Dams. Data are presented graphically only. The yield of overflow pollutants is shown to be directly related to dry weather storage time. Copies are available for study but not for distribution.

Stewart, R. K. 1968. Biological Aspects of Water Quality: Charles River and Boston Harbor, Massachusetts. U.S. Dept. of Interior. Federal Water Pollution Control Admin. Technical Advisory and Investigations Branch, Cincinnati, Ohio. 39 pp.

A companion to Runas and Resi (1968), this volume covers the same survey from the biotic standpoint. The report on the Charles River contains a narrative summary. There are graphs of species diversity, total accumulations. It was noted that large portions of the seabed are completely devoid of benthos. Kinds of fouling organisms and the presence of an occasional winter flounder (*Pseudopleuronectes americanus*) are also noted. The deposition of "sludge" and presence of other polluted conditions are described. The report is not sufficiently detailed (no charts or numerical data) to be of particular importance. Copies are available for general distribution.

Tennant, P. A. and W. R. Jobin. 1970. Mystic River Study, 1967. Part A: Data Record on Water Quality. Massachusetts Water Resources Commission. Division of Water Pollution Control. Boston, Mass. 10 pp.

This report contains results of a survey conducted on 29 and 31 August and 12 and 14 September covering 16 miles of the Mystic and Aberjona Rivers from the source of the Aberjona in Reading, Massachusetts to the Amelia Earhart Dam in Everett, Massachusetts. Samples were collected at nine stations. Format and reported results of chemical, bacteriological and biological analyses are essentially the same as Part A in Ferullo, Molleux and Jobin, (1971). Copies are available on request.

Tennant, P. A., J. B. Casazza and W. R. Jobin. 1970.
Ipswich River Study, 1968. Massachusetts Water Resources
 Commission Division of Water Pollution Control. Boston,
 Mass. 43 pp.

A data record of water quality similar to the one cited immediately above is contained in the Appendix. The survey was conducted in August, 1968, and involved 7 freshwater stations. In addition, four sites on the tidal reach of the river (final 3.2 miles) were sampled for: five-day B.O.D. solids, pH, alkalinity, total phosphates, dissolved oxygen, nitrate, chlorides, and coliform bacteria. A surface profile and graphical phytoplankton density, density of pollution tolerant "Sludgeworms" (*Tubifex* spp.), inorganic nitrogen and phosphorous, and percent organic carbon. The section on Boston Harbor and the other tributary rivers deals with polychaete and phytoplankton densities, and descriptions of the bottom conditions including species present. Numerical data are tabulated in the Appendix. Table 21 gives a sediment core profile of organic carbon and nitrogen for three Boston Harbor stations. Copies of this publication are no longer in stock. Copies are available for study at the EPA library, Kennedy Building, Boston, Mass.

Stone and Webster Engineering Corporation. 1970. "Hydro-thermal Field Survey". Appendix C in U.S. Army Corps of Engineers Draft Environmental Statement, Addition of Unit No. 7, Mystic Electric Generating Station, Everett Mass. U.S. Army Engineer Division, New England. Waltham, Mass. 32 pp.

This report contains data on morphometry, current patterns, temperature profiles and a dye recirculation study. Studies were conducted during fall 1970 and were limited to a small area between the Tobin (Mystic River) and Alford Street Bridges. Copies are not available for general distribution.

TCE, Incorporated. 1973. Structural Evaluations and Ecological Observations in Boston Harbor. Presented to Engineering Division, MDC. March, 1973.

This report describes structural inspections of sea floor appurtenances to the MDC sewage treatment facilities carried out between 7 April and 30 August 1972 at fifteen sites in Boston Harbor. Ecological observations of the bottom fauna were made in conjunction with these structural investigations and in areas of known or suspected sludge display of water quality parameters are presented. Copies are available on request.

U.S. Dept. of the Interior. Geological Survey. 1971.
1970 Water Resources Data for Massachusetts, New Hampshire, Rhode Island, Vermont. Part I. Surface Water Records. Part 2. Water Quality Records. 373 pp.

Part 1. Contains daily records of stream discharge for three gaging stations on the Charles River, two on the Neponset River and one each on the Aberjona River, Mother Brook and Old Swamp River (near South Weymouth, Massachusetts).

Part 2. Contains chemical analyses, identical in type to Brackley, Fleck and Willey, (1973), for 28 sampling sites on the Charles River. In addition there are data on concentrations of dissolved arsenic, boron, cadmium, cobalt, copper, chromium, lithium, lead mercury, nickel, strontium, and zinc for six sampling sites on the Charles River.

Similar reports on water resources data are published for every year beginning with 1964. Copies are available on request.

U.S. Army, Corps of Engineers, New England Division, 1973.
Draft Environmental Statement: Addition of Unit No. 7.
Mystic Electric Generating Station, Everett, Mass.
 June, 1973. Waltham, Mass.

Certain portions of this report, namely Table 2-6, and Sections 2.8 and 3.2.3, summarize the results of the Marine Environmental Services investigations. Also reported (Section 3.2.1.2.2) are the results of a screen well monitoring program. Some indication of relative abundance of various animal forms can be inferred from the screen wash collections. Copies are not available for general distribution.

U.S. Army Corps of Engineers. New England Division. 1973.
Final Environmental Statement: Charles River Dam,
Boston, Massachusetts July, 1973. Waltham, Mass.

A summary of analyses of potential dredge spoil is presented on page 36. Maximum, minimum and average values for: volatile solids, C.O.D., total Kjeldahl nitrogen, oil and grease, mercury, lead, zinc, and copper are given for five samples obtained from the Lower Charles River Basin in May 1972 and for ten samples obtained in July 1972. The July samples were taken from deeper horizons (down to 10 feet) than the May samples (upper 2 inches). Copies are available in limited quantity.

U.S. Dept. of the Interior. Federal Water Pollution Control Admin. 1968. Proceedings: Conference in the Matter of Pollution of the Navigable Waters of Boston Harbor and its Tributaries, May 20, 1968. Boston, Mass. 369 pp.

In addition to transcripts of discussions of the participants there are two important enclosures: "Report on Pollution of the Navigable Waters of Boston Harbor" contains data on major municipal discharges (quantities, coliforms) and status of the shellfisheries. Other data are summarized or reprinted from Runas and Resi (1968)

and Stewart (1968). "Boston Building Department Progress Report on Harbor Pollution Survey" contains data on sources of solid waste and chemical, petroleum and sewage waste pollution (by percentage). This report also contains a comprehensive summary of the reports by Runas and Resi (1968) and by Stewart (1968). Copies are available in limited quantity.

U.S. Dept. of the Interior. Federal Water Pollution Control Admin. 1969. Proceedings: Conference in the Matter of the Navigable Waters of Boston Harbor and its Tributaries, Second Session. April 30, 1969. Boston, Mass. 347 pp.

The major portion of this document consists of a report entitled: "Joint Report on Pollution of the Navigable Waters of Boston Harbor". The report begins with an evaluation of the pollution status of various portions of the Harbor. A discussion and list of pollution sources follows. The results of a chemical bacteriological and biological survey conducted from May to August 1968 and involving 51 stations (all marine) are presented. Comparisons are made with findings of the 1967 survey (Runas and Resi, 1968; Stewart, 1968). In the 1968 study, analyses were performed on samples for dissolved oxygen, salinity, nitrate as nitrogen, total orthophosphate, and total and fecal coliform bacteria. A survey of benthic invertebrates was also conducted at 22 of the 51 stations and organisms were identified to species. Actual species counts are displayed in Appendix C. Total zooplankton and phytoplankton densities were investigated at selected stations throughout the summer. Appendix D lists the planktonic forms found by taxonomic classification, but otherwise all data are represented as counts of both total animal and total plant organisms. An area by area summary of the biological findings is provided. Copies of this document are no longer in stock but are available for study at the EPA library, Boston, Massachusetts.

U.S. Dept. of the Interior. Federal Water Pollution Control Admin. 1970. Water Quality Management Study, Boston Harbor, Massachusetts: Projections of Population and Municipal Waste Landings. New England Basins Office, Needham Heights, Mass. 21 pp.

This report projects future impacts of sewage discharges in terms of influent and effluent volumes and biological oxygen demand (B.O.D.) only. The eastern Massachusetts metropolitan area (EMMA) is covered. B.O.D. loading of discharged sludge is not included. Copies are available from the EPA, Boston, Massachusetts.

U.S. Environmental Protection Agency. 1971. Charles River Water Quality Study. Appendix E of Charles River Study. Boston, Massachusetts. 136 pp.

Advantages of, requirements for, and alternatives to augmentation of low stream flows are considered. Included in the discussion are alternative plans for siting sewage treatment plants, for waste water diversion to Boston Harbor, and for subsurface disposal of sewage waste. Existing water quality conditions are summarized drawing upon data from surveys conducted in 1967 (see: Runas and Resi, 1968; Stewart, 1968; Ferullo et al., 1971) and in 1969 (see: Unpublished material, U.S. Dept. Int. FWQA, 1969). Projected wasteloadings are expressed in terms of five-day B.O.D. and discharge volumes. The quantities of flow augmentation necessary to maintain a dissolved oxygen level of 5.0 mg/l. were computed for waste loading conditions in 1980, 2000 and 2020, assuming 90 percent removal of five-day B.O.D. A figure shows projected dissolved oxygen profiles for the 70 mile length of the river from Milford to Charles River Dam. Availability of copies is limited.

U.S. Environmental Protection Agency. 1971. Interim Report on Combined Sewer Overflows in Boston Harbor. Prepared for New England River Basins Commission, Boston Harbor Coordinating Group. Boston, Massachusetts.

The overflow volume, average five-day B.O.D. and average coliform count expected from 21 overflow sources in the Boston Harbor drainage area are calculated for 5, 10 and 15 year frequency of rainfall for the years 1970, 1995, and 2020. It is also shown that a rainfall intensity of less than 0.03 inches per hour is sufficient to produce overflow in some of the area combined sewers. By 1995 one sewer system will be unable to handle even the dry weather flows. A map shows shoreline areas affected by the combined sewer overflows. Plans for remedial action are outlined. Copies are available in limited quantity.

U.S. Environmental Protection Agency. 1971. Proceedings: Conference in the Matter of Pollution of the Navigable Waters of Boston Harbor and its Tributaries. Third Session, October 27, 1971. Boston, Massachusetts. 327 pp.

Contained herein is a report of the Massachusetts Department of Public Health regarding the bacteriological survey of the five Dorchester Bay Beaches from July to September, 1970. The report includes evaluations of the influence on bacterial counts of contiguous local sewer discharges, tidal stage, rainfall and other meteorological conditions. Five to ten stations were sampled at each beach for total and fecal coliforms. In addition there were four sample stations in the Neponset River estuary. Evidence of tidal influence on bacterial quality was shown at four of the

five beaches. At many stations, more than a third of the samples taken exceeded public health bacteriological guidelines. Copies are available in limited quantity.

UNPUBLISHED MATERIAL

This section includes a variety of material including university theses, manuscripts, and papers delivered before society meetings. Material originally in mimeograph or typewritten form is so indicated in parentheses following the citation. Except as noted, the documents in this section were intended for limited distribution at best and may be reliably obtained only from files at the original source.

Bumpus, D. F., W. S. Butcher, W. D. Athern and C. G. Day.
1953. "Inshore survey project: Boston. Final Harbor Report". Woods Hole Oceanographic Institution. Reference No. 53-20. March, 1953. 39 pp. (mimeographed).

This report is still useful since it contains data on sediments underlying Boston Harbor which are otherwise rare. Rates of sedimentation, residence and flushing times for suspended matter are given. Analysis of bottom samples, and cores for density, water and organic content and color are presented. Other data presented are in keeping with harbor defense requirements for which purpose the report was prepared. Xerox copies may be obtained from WHOI library (10 cents per page).

Collier, R. and others. 1972. "Determination of a General River Model through the Processing of Analysis Data on Chemical and Physical Parameters Affected by the Environment". Massachusetts Institute of Technology. Dept. of Earth and Planetary Sciences, Cambridge, Mass. (typewritten).

This student project was conducted from June through August and involved analyses of phosphate, nitrite, chloride, sodium, potassium, calcium, and magnesium concentration levels at 17 stations on the Mystic River, 6 stations on the Parker River, 14 stations on the Ipswich River and 28 stations on the Merrimack River (20 in New Hampshire). Diatom and coliform counts were also included at a few stations. Stream flows are given, utilizing existing U.S.G.S. gauging stations. A subsequent report is also being prepared which will deal specifically with the Merrimack estuary and include data on C.O.D. and ferrous and ferric iron species as well as the constituents previously listed.

Wood, K. H. 1971. Water Quality Committee Report - 1970.
Charles River Watershed Association. Newton, Mass. 6 pp.

Water was sampled monthly at 21 stations on the River from Milford downstream to Cambridge beginning in July and ending in November. The report presents averages of the analyses (total coliforms, pH, turbidity, color, nitrates, ammonia, phosphates, C.O.D. and chlorides) for each station. An explanation of the significance of each of the constituents or parameters measured (including acceptable levels by Massachusetts classification standards) follows the data presentation. Copies are no longer available for distribution. Since the report is brief, a Xerox copy might be obtained with the author's permission at the Massachusetts Water Resources Commission.

Wood, K. H. 1972. Water Quality Committee Report - 1971.
Charles River Watershed Association, Newton Mass. 6 pp.

This report represents a continuation of the study discussed above. This year the sampling was carried out from May through October; otherwise the program was the same. Following the table of averages is a narrative description and discussion of the conditions at each site with respect to pollutants. The general conclusion of this second year study was that conditions had not changed appreciably from the previous year. No further Association studies of this scope have been carried out. Availability of the previous report applies.

Commonwealth of Massachusetts. 1970. "Report of the Metropolitan District Commission Relative to the Sanitary Condition of the Charles River Basin". (typewritten).

Samples taken at eight stations in January through May are compared to samples taken during the previous four years on the basis of dissolved oxygen content, B.O.D., and coliform counts. Samples taken in 1970 show marked improvement over previous years. However, it should be noted that in all previous years the sampling was done in June through November. A separate table shows average, maximum and minimum values for: temperature, depth, dissolved oxygen, salinity, B.O.D., pH, color, chlorine demand, coliform count, chlorides, total solids and suspended solids for each of the eight stations.

Commonwealth of Massachusetts. 1968. "Preliminary Boston Harbor Otter Trawl Survey, March, 1968". Dept. of Natural Resources, Division of Marine Fisheries. (typewritten).

This brief paper presents the results of a trawl survey conducted on 21, 28 and 29 March. Ten tows were made along transects running generally from Point Allerton in Jull to the Northern tip of Revere Beach. Substantial quantities of winter flounder were

captured in Outer Boston Harbor. Eight other species of firfish and an occasional lobster (usually under legal size) were also caught. None except the flounder were present in any quantity.

Ferullo, A. F. 1972. "The Charles River: Water Use Classification, Pollution Sources and loadings". Paper presented before the American Chemical Society. Division of Water, Air and Waste Chemistry, Boston, Mass. April, 1972. (mimeographed).

This paper was based primarily on the findings in Ferullo, Moleux and Jobin (1971). Some of the tables are reproduced from the 1971 document. A computer model was used to project future phosphorous and B.O.D. loadings. By 1980, the assimilative capacity of the Upper Charles River was predicted to be 1530 pounds of five-day B.O.D. per day. Ninety percent removal of B.O.D. and 2 to 5 mg O_2/l . in the discharged effluent would be required to meet assigned water quality criteria. By the year 2000 requirements for effluent would be raised to 98 percent B.O.D. removal and 7.6 mg O_2/l .

Cassidy, R. A. 1971. "The upper Mystic Lake: History, Recreational Use, Ecology." Tufts University. 50 pp. (typewritten).

This student paper presents geological history, history of modifications by man, a list of aquatic vegetation (from 1949 Fish and Game survey) and early (pre 1949) finfish stocking programs. A 1970 Massachusetts Division of Fisheries and Game report is quoted as describing the lake as a stressful environment for trout. Three major sources of pollution are cited: (1) Aberjona River (2) surface (storm) runoff and (3) septic system overflows.

DeFeo, F. L. 1971. "The Establishment and Operation of the Aberjona River Commission". M.S. Thesis. Tufts University. 99 pp (typewritten).

Included in the thesis are the results of a survey of local wastewater discharges (97 possible and confirmed sources are identified in Appendix D) and a water quality sampling program (stream flow, pH, alkalinity, acidity, B.O.D., chlorides, total and fecal coliforms) conducted during June and July 1971. One identified discharge was so acidic that it caused temporary pH values as low as 2.0 in the river.

Elion, G. R. 1970. "Pollution in the Lower Mystic Lakes". Tufts University (Typewritten).

This student paper includes a summary of a 14-month study on Lower Mystic Lake in Arlington and Medford, Massachusetts (flow rates, dissolved oxygen, B.O.D., coliform counts, oil and detergent foams, and a computerical mass balance model). Using field

and laboratory data the investigation concluded that a proposed scheme of aeration would cause undesirable ecological side effects unless 0.01 grams per liter copper sulfate is added during the aeration process to suppress algal blooms. At the end of the paper is an inventory of microscopic and macro-invertebrate fauna and summary of the MDC program to renovate Lower Mystic Lake.

Harrington, J. J. 1972. "Charles River Basin Reclamation Program". Paper presented before the American Chemical Society. Division of Water, Air and Waste Chemistry. Boston, Mass. April, 1972. (mimeographed).

The general condition of the river with respect to pollution is discussed. Four major factors contributing to the grossly polluted condition are described: (1) quality of water flowing over Watertown Dam, (2) overflow from combined sewers, (3) bottom conditions in Lower Basin and (4) retention of highly polluted bottom waters at the Charles River Dam. Corrective measures are suggested. The report calls for field studies of the pollutant accumulations and proposes a four phase program to counter the pollution problems.

Harris, R. H. 1972. "Water Quality in the Charles River Basin". Paper presented before the American Chemical Society. Division of Water, Air, and Waste Chemistry, Boston, Mass. April, 1972 (mimeographed).

This paper provides an excellent summary of limnological conditions in the Lower Charles River. Eight figures accompany the narrative and provide a graphical display of basin morphometry and variations of temperature, chlorides, ammonia, nitrates, total phosphate and oxygen concentration with depth. The Basin is highly stratified and very little vertical mixing takes place. Constituents of the hypolimnion (water at depths of more than ten feet below the surface) may remain for an indefinite period.

Mystic River Watershed Association, Inc. 1970. "The Environmental Quality of the Mystic River Basin". Mystic River Watershed Symposium. Vol. I. 26 pp. (mimeographed).

This report summarizes the pollution problems facing the watershed including leaching from road salt stores, reduced stream flow due to water supply demand, and sewage overflow. The appendix gives temperature, pH and coliform counts for 14 stations from the Aberjona River to Somerville sampled in the first four months of 1970.

Mystic River Watershed Association, Inc. 1971. "Student Reports on the Environmental Quality of the Aberjona River, Upper Mystic Lake, Alewife Brook, Mill Brook, and

Mystic River". Mystic River Watershed Symposium.
Vol. II. 18 pp. (mimeographed).

A report of student pollution survey activities is included for each of the water bodies listed in the title. The reports are narrative and qualitative except for data on pH, coliform counts, and chloride analysis on Upper Mystic Lake. The main objective of the reports appeared to be description of pollution sources.

Kroesser, F. W. and D. R. Turner. 1972. "Mystic River Watershed Association, Inc. Water Quality Report".
Mystic River Watershed Symposium. Vol. III 16 pp.
(mimeographed).

This report describes monitoring programs conducted on the Mystic River since 1967 including studies by agencies of the Commonwealth of Massachusetts and by Habitat Inc., Belmont, Massachusetts. Data available from these studies (coliform counts, B.O.D., pH, chlorides, ammonia, total nitrogen and phosphate) are presented in a table. A discussion of the significance of the data and recommendations for further studies follows the table.

Issac, R. A. and J. Delaney. 1972. "Toxic Element Survey. Progress Report No. 1". Massachusetts Water Resources Commission. Division of Water Pollution Control.
25 pp. (typewritten).

This report, not yet submitted for publication approval, contains the results of trace metal analyses on hundreds of samples taken from bottom sediments, shellfish, finfish and surface waters in both fresh and marine environments. Samples were analyzed for volatile solids and for arsenic, cadmium, chromium, copper, mercury, nickel, lead, and zinc by atomic absorption spectrometry. "Alert levels" (values judged substantially higher than background by the EPA) are listed for six heavy metals for oysters, quahogs and soft-shell clams. Ranges and median values are given for concentrations of metals in wastewater sludges from 22 treatment plants. Trace metal concentration levels from waters with a wide range of pollution loads are compared in a table. The distribution of trace metals with depth in Boston Harbor and Lake Quinsigamond sediments is portrayed.

Jason Cortell and Associates, Inc., Ecosystems Division.
1972. "Fowl Meadow Marsh: Natural Resources Inventory".
Commonwealth of Massachusetts. Dept. of Public Works.
Boston Transportation Planning Review. 150 pp. and
appendices 1-3 (typewritten).

This is an intensive study of the Neponset River ecosystem at the intersection of Interstate Route 95 with State Route 128. While the study area includes only a few square miles, it goes far beyond the scope of any other environmental study in the Boston

Metropolitan area. It is the only study, except for the Marine Environmental Services' Mystic River Ecological Field Surveys, which inventories benthic invertebrate populations. Geological profiles, a detailed soils map, and other data on surficial and bed-rock geology are provided, as well as climatological meteorological information. Forty six water samples were collected in the study area. Analyses of the following dissolved constituents are given: ammonia, carbon dioxide, chlorides, iron, orthophosphate, sodium and sulfate. Of the trace metal components, only zinc levels are analyzed. Coliform counts were also taken. The abundance of aquatic fauna including finfish was inventoried. A botanical inventory was also made. Types of wildlife frequenting the area are listed along with comments on pertinent aspects of the natural history.

Ketchum, B. H. 1951. "The Dispersion and Fate of Pollution Discharged into Tidal Waters and the Viability of Enteric Bacteria in the Sea". Woods Hole Oceanographic Institution. Reference No. 51-16. 16 pp. (mimeographed).

This older study includes exchange ratios and coefficients of accumulation of sewage waste calculated for Boston Inner Harbor, Dorchester Bay, and President Roads before the Present Nut Island and Deer Island sewage treatment facilities became operational. Nevertheless, the discussion of sea water bacteriocidal activity and impact of sewage on natural plankton populations may be useful background information. Xerox copies may be obtained from WHOI library (10 cents per page).

McLeod, G. C. and G. E. Foss. 1971. "The Measurement of Natural Resources: the Pattern and Significance of Effluent Discharge into an Estuary". New England Aquarium Corporation. 16 pp. (typewritten).

The report describes a method of monitoring the dispersal of effluent and sludge discharges from MDC sewage treatment plants using a data collection buoy moored at the edge of President Roads in Boston Harbor. The influence of the discharge on the biology and chemistry of Boston Harbor is discussed in general terms. One example of the biological impact is the low diversity of the phytoplankton community; five (tolerant) species are dominant. A qualitative description of benthic (sludge) deposits in Boston Harbor is provided.

Process Research, Inc. 1969. "Charles River Reclamation. A proposal to the Commonwealth of Massachusetts". 140 pp.

Included with a report on the operation of a pilot sewage treatment plant is a report on results of a water sampling program. Sixteen stations were sampled once a week from mid June to mid August 1969 at depth intervals of one to two feet, in the Lower Basin, between Watertown and Charles River Dams. The data included are in the form of graphic computer displays of mean values by depth

(vertical axis) and river length (horizontal axis).

Parameters displayed are: temperature, chlorides, dissolved oxygen, ammonia, nitrate, and phosphate. The conclusion is reached that impoundment has led to the stratification of the river into an upper "epilimnion" and lower "hypolimnion" (characteristic of a stratified lake). The epilimnion is warm (up to 27°C), turbid, and contains moderate amounts of nitrogen and phosphorous as well as adequate levels of dissolved oxygen. The epilimnion supports a substantial amount of algal growth. The hypolimnion is saline (up to 17×10^3 ppm chloride at Charles River Dam), cool (approximately 18°C), high in nutrients (up to 6 ppm ammonia, 1.5 ppm nitrate and 5.5 ppm phosphate) and has very little oxygen (average, 0.5 ppm) and a low pH value. This bottom water mass is seldom overturned or flushed. This is one of few studies in the Boston area which presents a complete vertical profile of chemical constituents.

U.S. Dept. of the Interior. Federal Water Pollution Control Administration. 1968. "Radioactivity Levels in the Charles River and Boston Harbor, Massachusetts". Technical Advisory and Investigations Branch, Cincinnati, Ohio. 13 pp.

A program of water and bottom sediment sampling was conducted in conjunction with the comprehensive water quality study of July and August 1967 (see Runas and Resi, 1968) to determine existing radioactivity levels in Boston Harbor, Charles River and seven other tributaries to the Harbor. Activity of uranium, lead-210, radium 226, and strontium-90 was reported in picocuries. Levels of natural materials (uranium, radium, and lead) and fallout material (represented by strontium-90) were generally found to be low. This constitutes the only known survey of radioactivity in the Boston area.

U.S. Department of the Interior. Bureau of Sport Fisheries and Wildlife. Fish and Wildlife Service. 1972. Letter to Division Engineer, U.S. Army Corps of Engineers, New England Division, 25 July, 1972. 26 pp.

The letter comments on the status of fisheries in the Charles River, in particular conditions with respect to particular anadromous and cold water (trout) species are described. The most common species of fish and wildlife associated with the river are listed.

U.S. Department of the Interior. Bureau of Sport Fisheries and Wildlife. Fish and Wildlife Service. 1971. Letter to Division Engineer, U.S. Army Corps of Engineers, New England Division, 20 September, 1971. 10 pp.

This letter comments on the conditions of the Charles River

fishery with respect to population size, species present, impediments to migration and unfavorable habitat.

U.S. Department of the Interior. Federal Water Quality Administration. 1969. "Water Quality Survey of the Charles River, August, 1969". Technical Advisory and Investigations Branch, Cincinnati, Ohio.

Samples were collected at six sites along the river from the Milford-Hopedale town line to the lower Charles River Basin. Samples were analyzed for temperature, dissolved oxygen, pH, turbidity, color, nitrates, organic nitrogen, ammonia, total and soluble phosphorous, coliform bacteria, alkalinity, B.O.D. and suspended solids. In addition, two of the stations were continuously monitored for dissolved oxygen and temperature in order to establish a diurnal curve for each locality.

Walker, W. W. 1971. "A Pollution Model of the Charles River Basin". M.S. Thesis. Mass. Instit. of Technol. Dept. of Chem. Eng. 139 pp.

The model was devised to project expected distribution of carbonaceous B.O.D. sources, employing the mass balance concept and utilizing data on 5-day B.O.D. provided by the MDC. Results showed, for example, a 20 percent reduction in B.O.D. after the southern Charles River relief sewer was placed in operation. B.O.D. values were correlated with acreage served by sewer type. Results of the correlation showed that combined sewers contribute six times as much B.O.D. as separate sewers. Runoff accounts for 40 percent of the B.O.D., sewage flow accounts for 60 percent. Distributions of suspended solids, total nitrogen, total hydrolyzable phosphate, and coliform bacteria by source were determined. Runoff contributes a substantial portion of the total of these constituents, except in the case of coliform bacteria. A copy of this thesis is on file at MIT Science library.

White, R. J. 1972. The distribution and concentrations of selected metals in Boston Harbor Sediments. M.S. Thesis. Northeastern Univ., Dept. of Civil Engineering. 103p.

More than 150 sediment samples covering the entire Boston Harbor area from the Weir River estuary to Winthrop Bay, and including inner harbor area to the Mystic River estuary, were analyzed by atomic absorption analysis for percentage of volatile matter, cadmium, chromium, copper, lead, mercury, nickel, and zinc. Good correlations were observed between several of the different metals and organic content of the sediment. Metal concentrations decreased along a path extending from the Inner Harbor and western shore easterly out toward Massachusetts Bay, and southeasterly towards Nantasket. The Neponset River sediment had the highest metal concentrations of the Outer Harbor tributaries. Increased concentration of the metals occurred where circulation was restricted.

This study is the single most comprehensive study of trace metals in sediments of the area. A copy of the thesis is on file at the Northeastern University Library.

STUDIES IN PROGRESS

On-going studies cited here are limited to those involving original collection of water quality data. The list is quite short. Other groups may have plans for monitoring environmental quality which have not come to light in the author's brief search. Most of the studies mentioned are sponsored by state or municipal authorities. A notable exception is the New England Aquarium, whose monitoring research activities have considerably slackened since termination of their contract with the Massachusetts Department of Natural Resources.

Charles E. Maguire, Inc. Waltham, Massachusetts.

This firm is currently engaged in an engineering study of the impact of sewage treatment facilities recently installed by the town of Somerville. The study involves collection of water samples in and about the Mystic River to assess the pre- and post-treatment effects on water quality. Parameters to be measured are those included in the Commonwealth of Massachusetts water quality classification guidelines.

Commonwealth of Massachusetts. Metropolitan District Commission (MDC). Engineering Division. Boston, Massachusetts.

The Engineering Division periodically takes surface samples from streams in the Boston Metropolitan area for chemical and bacteriological analyses. Eighteen sites on the Charles River (from Charles River dam to South Natick, Massachusetts) and four sites on Mother Brook (diversion from the Charles to the Neponset River) are sampled approximately twice monthly (probably much less often during winter). Ten stations on the Mystic and Aberjona River (Mystic River Study) and two stations on Stony Brook (South Boston) are sampled approximately monthly. Samples are analyzed for temperature, dissolved oxygen, B.O.D., pH, color, chlorine demand, coliform counts, chlorides, total and suspended solids, except that there are additional analyses run on samples from the Upper Charles River (South Natick Massachusetts to Watertown Dam) for ammonia as nitrogen, total Kjeldahl nitrogen and total phosphate. The analyses performed in connection with the Mystic River Study are somewhat abbreviated. Results reported are limited to: temperature, dissolved oxygen, five-day B.O.D., coliform count, ammonia as nitrogen, total nitrogen, total phosphate, pH and chloride (analyses of solids and chlorine demand have been omitted).

All data from the above surveys are available in the form of

laboratory data sheets (Medford field laboratory) from the Division.

Commonwealth of Massachusetts Metropolitan District Commission
(MDC) Sewerage Division. Boston, Massachusetts.

Samples are taken for chemical and bacteriological analyses approximately twice monthly from May through October at 17 stations in Boston Harbor (including one station each in the Mystic, Chelsea, Charles and Neponset River estuaries and at the Junction of Fort Point Channel and Boston Inner Harbor). Data submitted to the Environmental Planning Division include: total orthophosphate, ammonia as nitrogen, total Kjeldahl nitrogen, fecal and total coliforms, dissolved oxygen, pH, chlorides, and trace metallic elements by atomic absorption spectrometry (arsenic, cadmium, copper, lead, nickel, mercury and zinc). Analyses are performed at the Deer Island treatment plant.

During summer, the Sewerage Division also monitors bacteriological (coliform) concentrations at all public beaches in the MDC area, from Hull to Nahant. The northern portion of the District area is monitored by the Deer Island group, the southern portion (from Quincy Bay, south) is handled by the Nut Island group. All data cited above are available in raw form from the Environmental Planning Division.

Mystic River Watershed Association, Inc. Dr. F. W. Kroesser,
Supervisor of Environmental Quality Monitoring. Tufts
University, Department of Chemical Engineering.

Dr. Kroesser and his organization are actively engaged in assisting and advising study efforts by the Massachusetts Department of Natural Resources and the MDC. In addition they carry out some sampling programs of their own. They are particularly interested in problems of ammonia concentration in Mystic Upper Lake, stratified salt water in Lower Lake and in flood control.

Mulligan, H. F., Assistant Professor of Botany, University
of New Hampshire, Durham.

Studies of marine phytoplankton have been conducted, in 1971 and 1972, under Dr. Mulligan's direction, covering the coastal waters of Massachusetts from Boston Harbor northward. Results of the plankton collections and chlorophyll a measurements (at least three stations in Boston Harbor were involved) will be forthcoming in two reports entitled, "Phytoplankton of Massachusetts Bay", and "Phytoplankton of the coastal waters, from Rye, New Hampshire, to Boston, Massachusetts". A preliminary assessment (personal communications, not necessarily the conclusions of the reports) suggests that Boston Harbor itself is an area of relatively high productivity; species diversity, however, is reduced. Diatoms dominate the net phytoplankton. *Skeletonema costatum* is the most frequently encountered species during the sustained summer bloom (cell densities up

to two million cells per liter were found). Phytoplankton found in Boston Harbor were similar to forms found throughout the study area; no unique species were encountered.

New England Aquarium Research Department. Boston, Massachusetts.

The department is currently investigating the feasibility of raising shellfish in Boston Harbor. The quality of the harbor water is sampled whenever measurements are made on the test populations. Samples of the shellfish are taken for analysis of trace metal uptake (copper, zinc, lead, nickel, cadmium and mercury).

Process Research, Inc. Cambridge, Massachusetts.

This environmental engineering firm is currently engaged in a study of combined sewer overflows into Dorchester Bay in Boston Harbor. The study is similar in general to that by Smith et al., (1972). The study is funded by the MDC.

Commonwealth of Massachusetts Metropolitan District Commission (MDC). Division of Parks and Recreation. Sport Fisheries Project.

A project to restore a cold water fishery in either or both of the Mystic Lakes is underway. The first phase is to reduce the considerable salinity and hydrogen sulfide content in the bottom waters (hypolimnion) by partially or completely overturning Lower Mystic Lake, using freshwater flow from Upper Mystic Lake to flush out the saline water. In addition to the use of a conductivity probe and performance of other water quality analyses (see under MDC, Engineering Division) the project has employed a density monitoring device (Geophysical Survey Associates, Inc. Billerica, Massachusetts) and is experimenting with a vacuum collection device to obtain samples of hydrogen sulfide.

EXISTING ENVIRONMENTAL DATA

WATER QUALITY

It is not the intent of this section of the report to present, in detail, all of the data and findings of the reports cited. Enough detail will be provided to allow the reader to grasp the sense, or essence, of existing conditions, especially with respect to parameters considered by the authors to play an important role in wastewater management. In many cases, only ranges or representative values will be given. Where the term representative values has been used, some manipulation of the data to exclude possible anomalous extremes is implied.

Dissolved Oxygen

Dissolved oxygen is not only one of the most important parameters for the well being of an aquatic community, it is also one of the most widely variable parameters in a freshwater system. Oxygen concentrations in slow moving streams usually reach their lowest levels during the warmest months of the year. Generally, a river location with a deep oxygen sag shows the widest variation in oxygen content. The conditions expressed in figures 8 through 12 represent measurements made in two out of the three warmest months (June, July and August) for the Charles, Ipswich, Mystic, Neponset and North rivers. The original data from which the figures were generated were obtained as part of recent Commonwealth of Massachusetts river studies. Dissolved oxygen measurements were made four times in a 24-hour period, for 3 or 4 days, so that approximately the full range of diurnal variation in oxygen content is included. The lower values (oxygen levels above 5.0 ppm occurring less than 50 percent of the time) indicate a polluted environment which is highly unpredictable in available oxygen, and therefore, unsuitable for a diverse aquatic community.

In heavily polluted standing waters such as the Mystic Lakes and the Lower Charles River Basin the surface waters may be well oxygenated while the bottom waters are literally devoid of oxygen. A typical vertical oxygen profile for the Lower Charles River is shown in Figure 13. In tidal waters (i.e. Boston Harbor and its associated estuaries) available oxygen is rarely a problem for marine life; studies generally show concentrations in the range of 5 to 6 ppm.

Organic Material

Representative B.O.D. levels for various regions of the eastern metropolitan area are given in Table 3. James (1965) gives

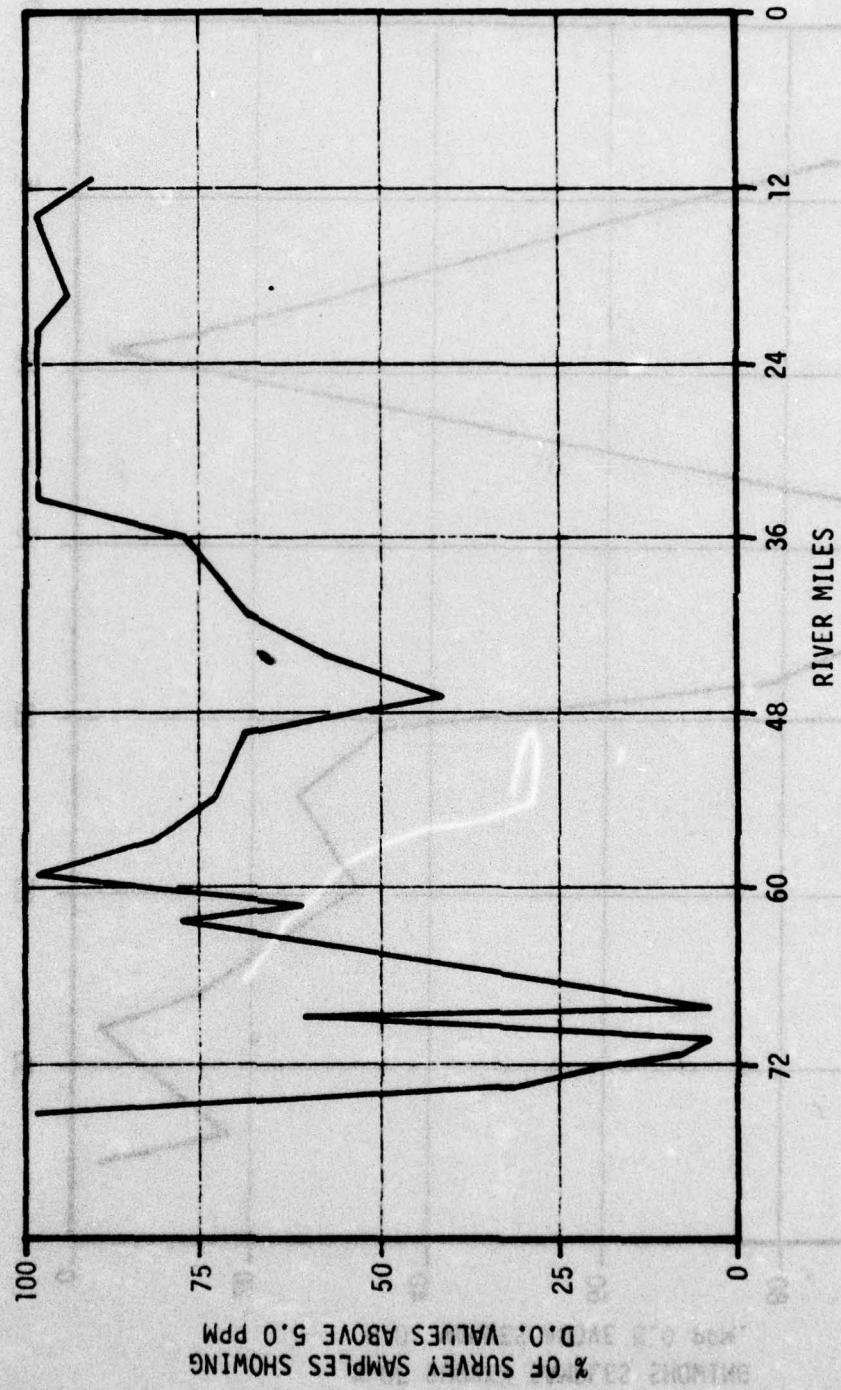


Figure 8. Horizontal profile of surface oxygen concentrations in the Charles River.

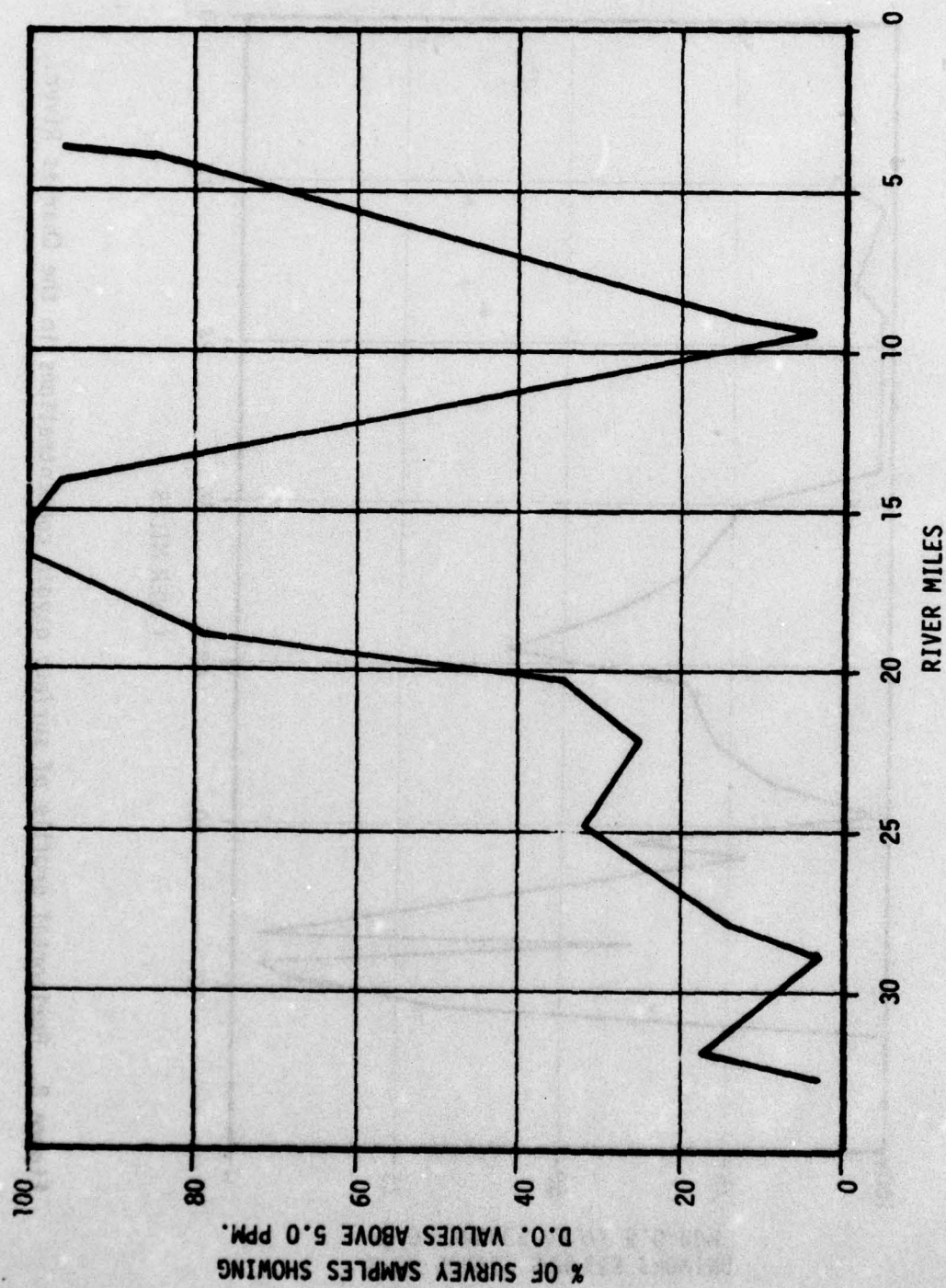


Figure 9. Horizontal profile of surface oxygen concentrations in the Ipswich River.

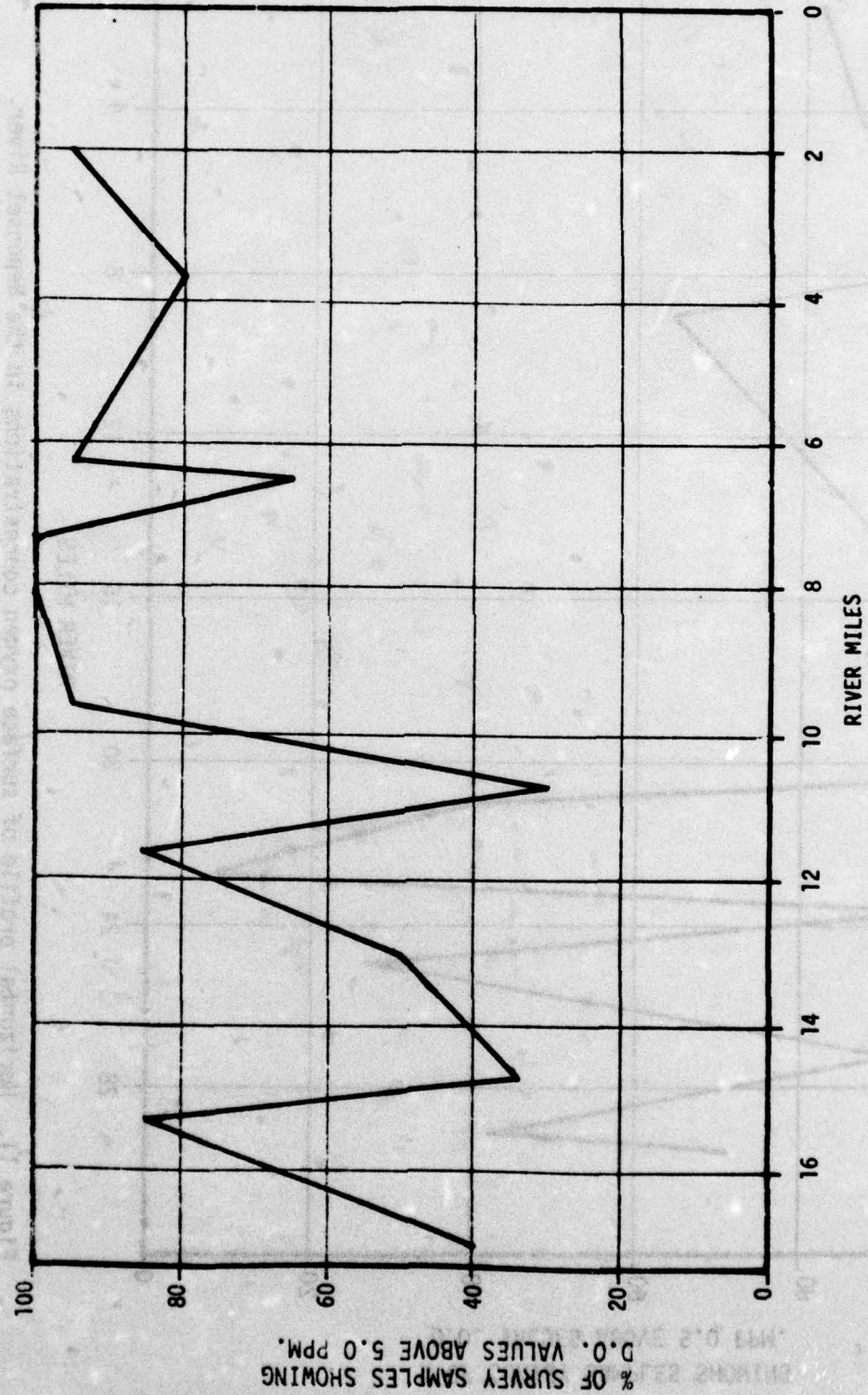


Figure 10. Horizontal profile of surface oxygen concentrations in the Mystic River.

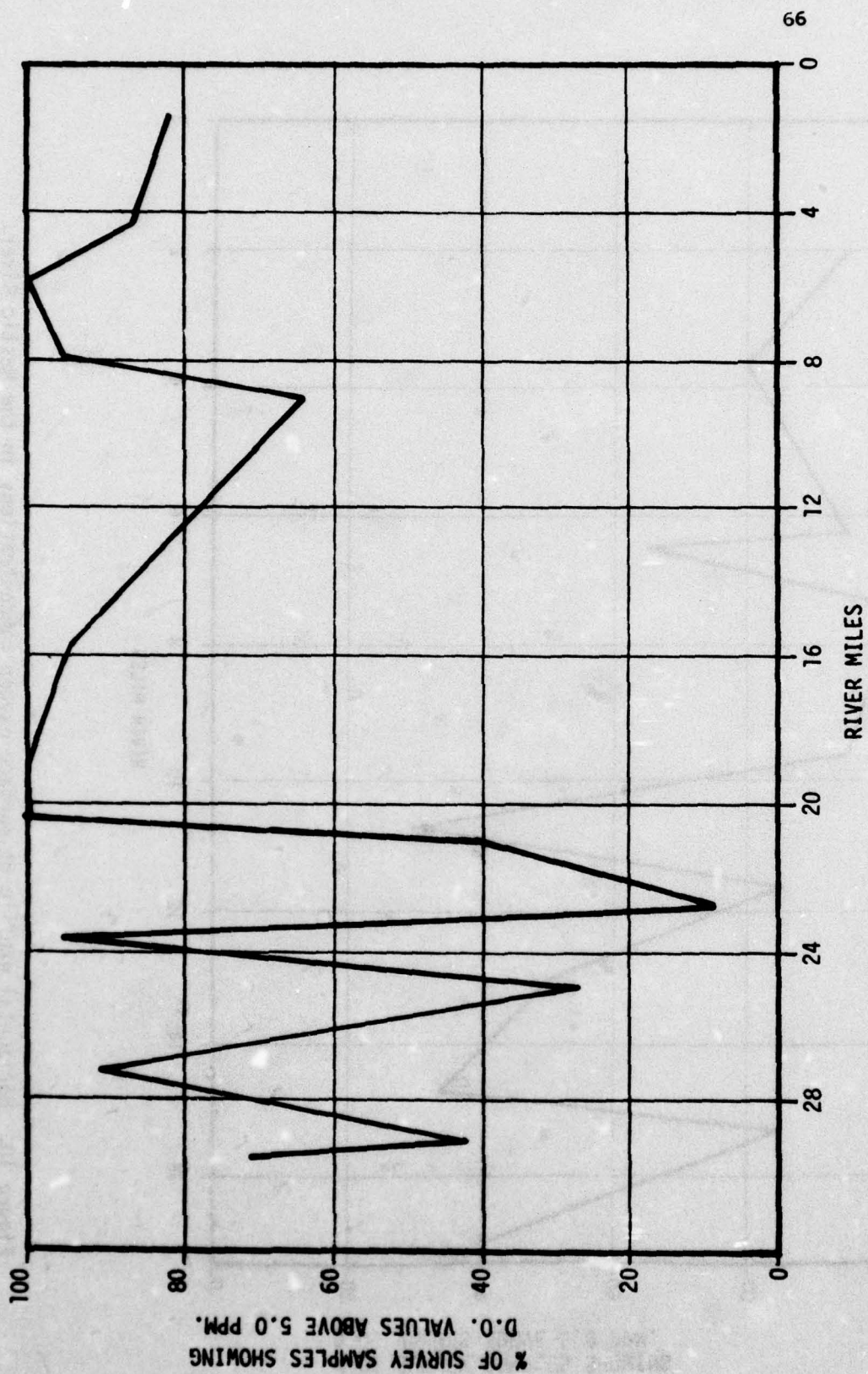


Figure 11. Horizontal profile of surface oxygen concentrations in the Neponset River.

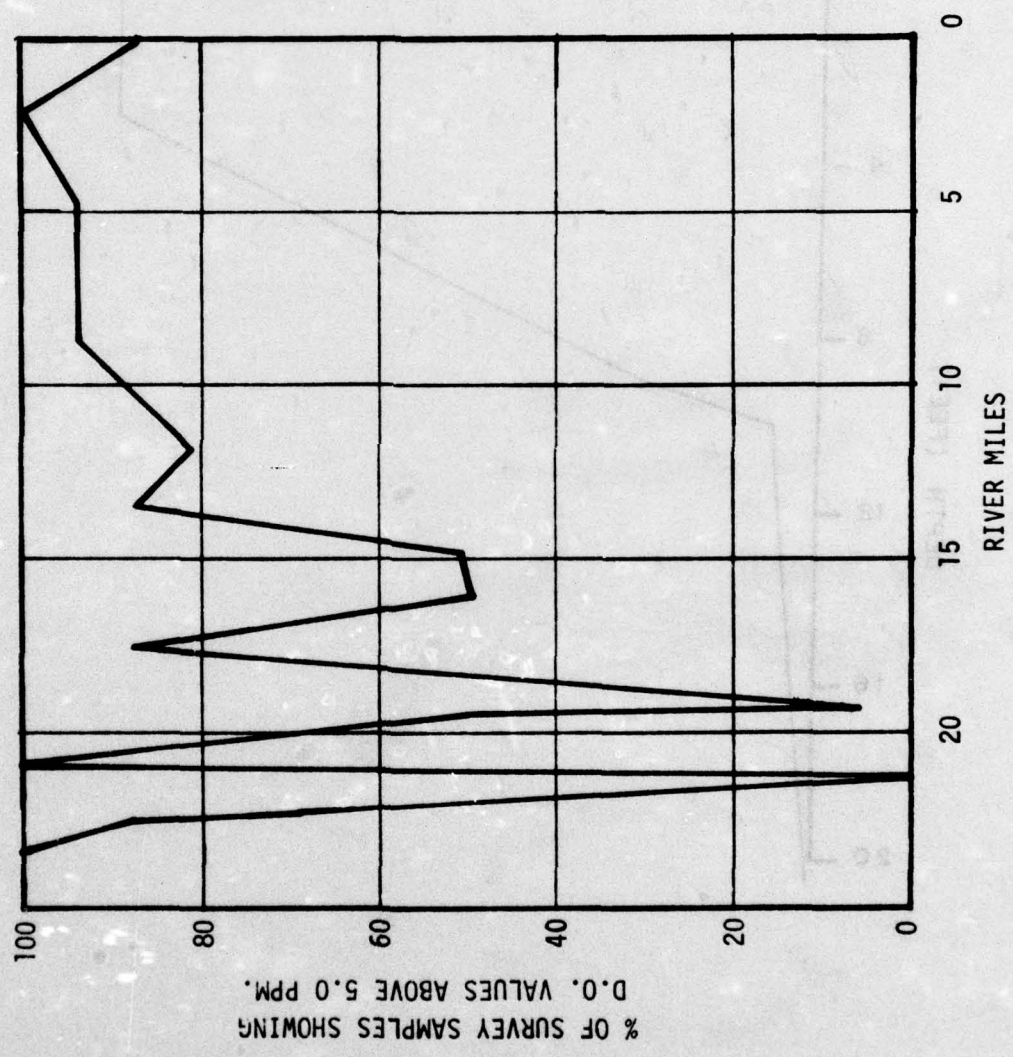


Figure 12. Horizontal profile of surface oxygen concentrations in the North River.

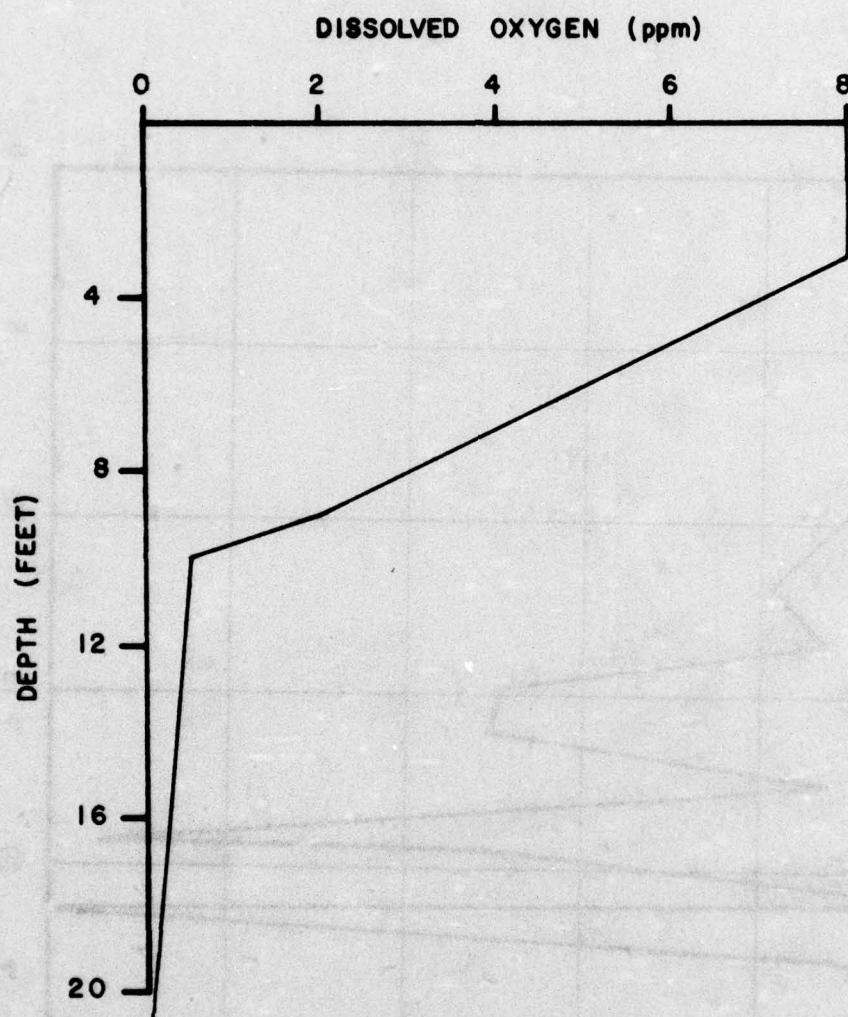


Figure 13. Vertical profile of dissolved oxygen concentration in the lower Charles River Basin, 150 feet from Charles River Dam (from Smith *et al.*, 1972).

TABLE 3. FIVE DAY BIOCHEMICAL OXYGEN DEMAND IN THE
EASTERN MASSACHUSETTS METROPOLITAN AREA

(Compiled From Massachusetts, Division Of
Water Pollution Control Surveys)

<u>Location</u>	<u>Representative Values (ppm)</u>
Boston Inner Harbor	2 - 9
Boston Outer Harbor	1 - 4
Mystic River Watershed	
Estuary (below Earhart Dam)	2 - 8
Mainstream (to Mystic Lakes)	4 - 9
Lower Mystic Lake	5 - 11
Upper Mystic Lake	2 - 5
Aberjona River	3 - 11
Charles River Watershed	
Charles River dam to Watertown Dam	3 - 5
Watertown Dam to Milford	2 - 20
Neponset River Watershed	
Estuary	1 - 3
Freshwater portion	2 - 6
Ipswich River	1 - 4
North River	1 - 20

the following interpretation:

Very clean water. . . .1 ppm B.O.D. or less

Clean. 1 - 2 ppm

Fairly clean. 2 - 3 ppm

Doubtful. 3 - 5 ppm

Bad. 10 ppm

Comparing this classification with the values presented in Table 3, it can be seen that water quality throughout much of the area is in the doubtful category, with respect to oxygen demand. In general, the sections of the river with the highest oxygen demand correspond with the regions of dissolved oxygen depression (see Figures 8 through 11). The waterways of the Mystic River system are in the poorest condition with many readings of 9 - 11 ppm. Fluctuations are less marked and the water quality somewhat better in the estuaries portions of the area, presumably due to dilution with cleaner seawater.

Much less attention has been given to C.O.D. (Chemical oxygen Demand) measurements than B.O.D. in the metropolitan area. C.O.D. is not included in either EPA or Division of Water Pollution Control reports. Considerable data on C.O.D. has been gathered for the Charles River, however, by Wood (1970, 1971). A half mile below the Milford sewage treatment plant C.O.D. values were 60 and 44 ppm for the years 1970 and 1971 respectively. In the Lower Charles River Basin values were 46 and 59 ppm. Wood (1970) indicated that faster moving portions of the stream might handle C.O.D. loads in the range of 50 ppm, whereas in a slow moving portion, the stream might have difficulty assimilating 5 ppm without appreciable oxygen depletion. No portion of the Charles River tested (from Milford to Cambridge) had C.O.D. levels less than 10 ppm. Values were commonly in the mid to high twenties.

Solid Particles

Turbidity measurements are not included in the most recent Division of Water Pollution Control surveys. As indicated by the older data, turbidities usually fall in the range of one to ten (Jackson or Formazin) units; the lowest values (two units or less) are typical of marine and stream headwaters. Values substantially above ten units, which would suggest increasingly intolerable light extinction and silting, were not recorded but might occur locally (e.g. during flood periods, dumping of "fill", or construction).

Measurements of suspended solids (filterable material) are included in most surveys. Table 4 gives representative values for the metropolitan area. All of the five principal streams of the area (Charles, Ipswich, Neponset, Mystic and North Rivers) contain large concentrations of suspended solids (30 ppm is the approximate level for secondary sewage effluent) over at least part of the stream course.

pH

In the less well buffered fresh water streams, pH values generally range from 6.3 to 7.8. According to the most recent data available from the Division of Water Pollution Control, the North River appears to be the most acid of the five principal river systems in the metropolitan area (pH 5.0 to 7.3); the Mystic River was the most alkaline (pH 6.7 to 8.0). The well buffered tide water areas have very stable pH values averaging about 7.8. Acceptable pH ranges are: 6.0 to 9.0 for freshwater aquatic life, and 6.5 to 8.5 for marine and estuarine life (EPA, 1973).

Alkalinity

As stated above, area streams generally have low buffering capacity except in regions of sea water influence. Total alkalinity, reported by the Division of Water Pollution Control, rarely exceeded 50 ppm except on the alkaline Mystic River (50 to 90 ppm) and in tide water regions (60 - 120 ppm). Values in the range of 20 to 40 ppm are typical of fresh water portions of area streams.

Coliform Bacteria

Data on coliform bacteria is commonly reported as total counts in one hundred milliliters of water. The total coliform count includes both fecal coliforms (originating in the intestinal tracts of warmblooded animals) and terrestrial coliforms (usually of lesser significance than the fecal types in urban areas). Counts in excess of 700 to 1000 are generally considered indicative of non-hygienic conditions. By this standard, skin contact with the water in any of the five principal waterways considered in this study should be avoided. One exception is the Upper Mystic Lake (count 10 to 700). Summer counts from other waterways, surveyed by the Division of Water Pollution Control, generally ranged from 1,000 to 200,000. Since coliform bacteria cannot survive for long in water, especially sea water (Ketchum, 1951), the count diminishes rapidly, away from sewage sources, in the tide water portion of the metropolitan area. In Boston Harbor, the lowest counts (10 - 400) are recorded to the south and seaward of the inner harbor.

**TABLE 4. SUSPENDED SOLIDS IN THE EASTERN
MASSACHUSETTS METROPOLITAN AREA**

(Compiled From Massachusetts, Division Of
Water Pollution Control Surveys)

<u>Location</u>	<u>Representative Values (ppm)</u>
Boston Inner Harbor	3 - 10
Boston Outer Harbor	2 - 8
Mystic River Watershed	
Estuary (below Earhart Dam)	11 - 30
Mainstream (to Mystic Lakes)	8 - 30
Lower Mystic Lake	8 - 15
Upper Mystic Lake	3 - 10
Aberjona River	6 - 20
Charles River Watershed	
Charles River Dam to Watertown Dam	9 - 23
Watertown Dam to Milford	15 - 30
Neponset River Watershed	
Estuary	4 - 47
Freshwater portion	7 - 12
Ipswich River	1 - 28
North River	4 - 30

Nitrogen

The principal nitrogen compounds available for plant growth (ammonia and nitrate) are shown in Table 5. Concentrations in excess of about one part per million indicate enrichment (eutrophication) of the stream waters, with the potential for sustaining substantial algal blooms, once these concentrations reach standing waters (cf. Vollenwieder, 1971; Jaworski et al. 1972). The Mystic River system in particular is over enriched. The principal source(s) of the excess nitrogen appear(s) to be the Aberjona River; the greatest concentrations of ammonia and nitrate occurred approximately 15 miles upstream from Boston Harbor (Commonwealth of Massachusetts, Mystic River Survey, 1973). The Charles and North Rivers also receive relatively high nitrogen loads in the upper regions of their basins (apparently related to the discharge from sewage treatment plants). Figure 14 is an example of an impounded section (the Lower Charles River Basin) which has received large quantities of ammonia nitrogen. Except in winter and early spring, prior to the annual vernal flowering (bloom), marine waters seldom contain appreciable quantities of ammonia or nitrite; soluble nitrogen compounds from fresh water streams and wastewater discharges appear to be fully utilized by marine primary producers.

Phosphorous

Quantitative measurements of this scarce element have been expressed as "total phosphorous" in recent Division of Water Pollution Control surveys (Table 6). Older surveys reported "orthophosphate" (the major constituent of total phosphorous) and "soluble" phosphate. Presumably, adoption of total phosphorous as a standard parameter will eliminate inconsistencies in analytical reporting which have heretofore plagued attempts to compare phosphorous data from one survey with another (cf. New England Aquarium Research Dept. 1973).

In studying the Potomac River, Jaworski et al. (1972) found phosphorous to be in "excess" at concentrations exceeding 0.15 ppm and, therefore, not limiting to the growth of plants; at concentrations below 0.04 ppm, however, total phosphorous appeared to be the limiting factor for plant growth. In general, phosphorous is not considered to be the limiting factor in the growth of marine plants.

The very large values for total phosphorous, cited in Table 6 for the Charles and North Rivers, are associated with sewage treatment plant outfalls in upstream regions. Impounded portions of nutrient laden waterways accumulate phosphorous in the bottom waters and sediments where the lack of sufficient solar

**TABLE 5. REPRESENTATIVE SUMMER SURFACE VALUES FOR
AVAILABLE NITROGEN IN THE EASTERN MASSACHUSETTS
METROPOLITAN AREA**

(Compiled From Massachusetts Division Of Water
Pollution Control And New England
Aquarium Research Department Surveys)

<u>Location</u>	<u>Ammonia as Nitrogen</u> (ppm)	<u>Nitrate as Nitrogen</u> (ppm)
Boston Inner Harbor	0.3 to 0.4	0.02 to 0.1
Boston Outer Harbor	0.01 to 0.3	.001 to .07
Mystic River Watershed		
Estuary		
(below Earhart Dam)	0.4 to 1.3	.03 to 0.6
Mainstream		
(to Mystic Lakes)	0.2 to 1.2	0.6 to 1.7
Lower Mystic Lake	0.3 to 1.3	1.4 to 2.0
Upper Mystic Lake	2.0 to 4.0	1.5 to 2.0
Aberjona River	0.1 to 15.0	0.4 to 2.0
Charles River Watershed		
Charles River Dam		
to Watertown Dam	0.2 to 0.5	0.1 to 0.4
Watertown Dam to		
Milford	0.1 to 4.0	0.1 to 2.5
Neponset River Watershed		
Estuary	0.2 to 0.3	0.02 to 0.1
Freshwater portion	0.3 to 0.5	0.2 to 0.5
Ipswich River	.08 to 0.4	0.2 to 0.5
North River	0.2 to 2.5	0.05 to 1.8

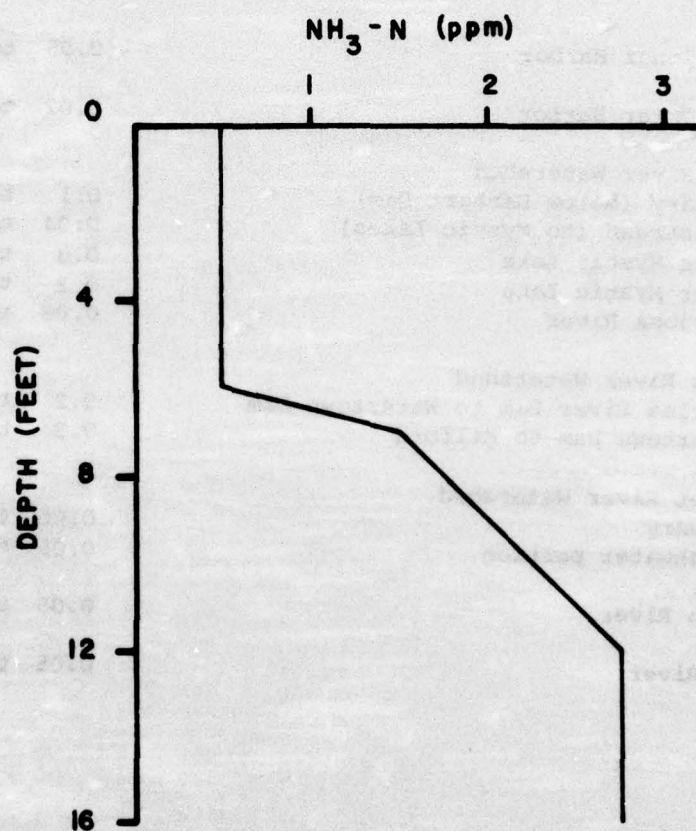


Figure 14. Vertical profile of ammonia nitrogen in the lower Charles River Basin, opposite a combined sewer overflow (from Smith *et al.*, 1972).

TABLE 6. REPRESENTATIVE SUMMER SURFACE VALUES FOR TOTAL PHOSPHOROUS IN THE EASTERN MASSACHUSETTS METROPOLITAN AREA

(Compiled From Massachusetts Division Of Water Pollution Control And New England Aquarium Research Department Surveys)

<u>Location</u>	<u>Total Phosphorous (ppm)</u>
Boston Inner Harbor	0.05 to 0.3
Boston Outer Harbor	0.02 to 0.1
Mystic River Watershed	
Estuary (below Earhart Dam)	0.1 to 0.2
Mainstream (to Mystic Lakes)	0.04 to 0.2
Lower Mystic Lake	0.3 to 0.4
Upper Mystic Lake	0.3 to 0.6
Aberjona River	0.06 to 0.1
Charles River Watershed	
Charles River Dam to Watertown Dam	0.2 to 0.6
Watertown Dam to Milford	0.3 to 4.0
Neponset River Watershed	
Estuary	0.06 to 0.1
Freshwater portion	0.05 to 0.3
Ipswich River	0.05 to 0.2
North River	0.05 to 3.0

radiation restricts plant growth to the margins. A typical profile for the Lower Charles River Basin is shown in Figure 15.

Chlorides

Chlorides, except for seawater, enter area waterways principally via road de-icing compounds. Tolerance to chloride depends principally on the cations present, an organism's body fluid salt content, and the organism's ability to regulate or control salt movement in and out of its cells. The principal cations associated with road salt are calcium and sodium. Of the two, calcium is the most frequently used and the most toxic (Wiebe, et al. 1934). Aquatic insects are much less tolerant of high chloride levels than finfish (Clemmens and Jones, 1954); lethal limits for some insects are within two or three parts per thousand (thousands of parts per million).

In the eastern metropolitan area, chloride concentrations approaching several parts per thousand have rarely been recorded, except in regions of sea water influence, such as tidewater portions of streams and behind the Charles River and Amelia Earhart (Mystic River) Dams. Chloride concentrations of up to 17 parts per thousand have been reported (Process Research Inc. 1969) at the base (inshore site) of the Charles River Dam (chloride concentration of seawater equals 19 parts per thousand). On the Aberjona River, chloride concentrations ranging from .060 to .450 parts per thousand have been measured (De Feo, 1971; Kioesser and Turner, 1972). Surface waters of the Mystic River lakes are reported to contain chloride in the range of one to three parts per thousand (Elion, 1970). Data relating to the lake bottom waters, which may have much greater chloride accumulations, are not available.

Chlorine

Chlorine is an exotic toxicant added to sewage effluent to control human pathogens. The lethal threshold concentration is on the order of 0.05 ppm for sensitive organisms in both fresh and marine waters (Zillich, 1972; Muchmore and Eppel, 1973). Residual chlorine concentrations of 0.2 ppm will kill adult fathead minnows (Zillich, 1972).

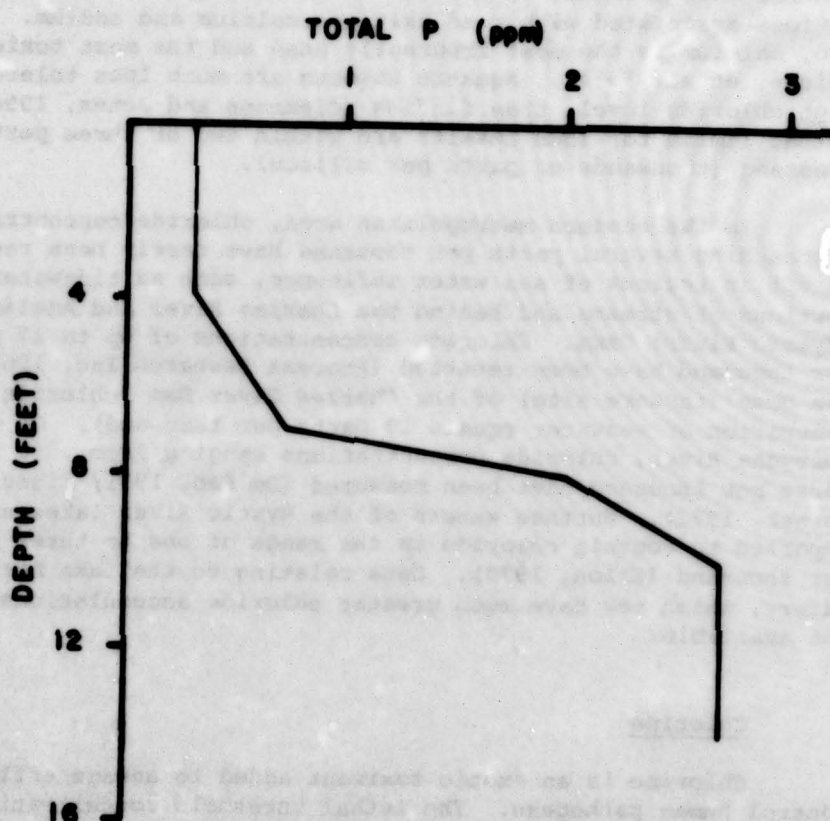


Figure 15. Vertical profile of total phosphorous in the lower Charles River Basin, near a sewage outfall (from Smith et.al. 1972).

Toxic Organic Constituents

Very little data exist concerning the nature of toxic organic materials which may be present in the waters of the area. Compounds which might be put in this category (such as hydrocarbons and organic biocides) are difficult and costly to analyze from water samples. They are usually somewhat easier to detect from living organisms or sediments in which the compounds eventually concentrate. The Division of Marine Fisheries has analyzed the pesticide content (DDT and derivatives) of certain marine organisms and sediments. Dr. Hites of MIT is developing mass spectrometric-gas chromatographic techniques to analyze water samples for long chain aliphatic compounds such as naphthalenes and phthalates (plasticizers). One study (Jason Cortel and Associates, Inc., 1972) has reported phenol levels in a short stretch of the Neponset River. These were in the range of 0.00 to 0.09 ppm.

Toxic Metals

The trace metal content of Boston Harbor waters has been reported by a New England Aquarium Research group (Gilbert et al., 1972). Scattered data is also available from various locations in the Charles River and a few other river basins (U.S. Geological Survey, 1971, 1972). The Massachusetts Division of Water Pollution Control has surveyed the North River (Scituate, Massachusetts) for trace metal content in 1971. Data compiled from these three sources is presented in Table 7, along with maximum acceptable values.

SEDIMENTS

Organic Material

As part of the intensive federal survey of July and August, 1967, the Federal Water Pollution Control Administration (predecessor of the Environmental Protection Agency) analyzed bottom sediments of the Charles River, Boston Harbor, and estuarine portions of harbor tributaries for organic carbon and nitrogen. Comparable data from a study of Lynn Harbor, and the Saugus and Pines River are available from Cochran and Gregory (1970). Data from these studies are shown in Table 8. Organic sediment index (OSI) is a term used by Ballinger and McKee (1971) for the product of percent-age organic carbon and nitrogen. An OSI greater than 0.5 was interpreted by these authors as indicating a high organic (pollution) load.

TABLE 7. MAXIMUM AND MINIMUM TOXIC METAL CONCENTRATIONS (ppb) FOR
SELECTED WATERS OF THE EASTERN MASSACHUSETTS METROPOLITAN AREA

<u>Location</u>	<u>Cadmium</u>	<u>Chromium</u>	<u>Copper</u>	<u>Lead</u>	<u>Mercury</u>	<u>Nickel</u>	<u>Zinc</u>
Boston Inner Harbor	0.3-0.5	1 - 4	3 - 7	2 - 11		7 - 14	24 - 62
Boston Outer Harbor	0.1-1.1	1 - 7	2 - 9	1 - 4		5 - 13	8 - 16
Charles River		0 - 2	0 - 30	2 - 7		2 - 4	0 - 20
North River	0 - 80	0 - 80	0 - 170	0 - 330	.05	0 - 540	0 - 340
Maximum Acceptable Levels (EPA, 1973)							
Marine & Estuarine	10	100	50	50	1	100	100
Fresh Water (hardness less than 100 ppm. CaCO ₃)	4	50	61	30	0.2	100 ²	4 ²

1 Safe concentration for reproduction and growth

2 Calculation based on multiplication of application factor by 96 hour LC₅₀ for fathead minnows

TABLE 8. MAXIMUM-MINIMUM VALUES FOR ORGANIC CONSTITUENTS IN SEDIMENTS
OF THE EASTERN METROPOLITAN AREA

(All values compiled from Stewart, 1968, except as noted below)

LOCATION	ORGANIC CARBON (% DRY WT.)	ORGANIC NITROGEN (% DRY WT.)	ORGANIC SEDIMENT INDEX (% C x % N)
Boston Inner Harbor	6 - 24	0.2 - 1.3	1.0 - 30
Boston Outer Harbor	2 - 5	0.1 - 0.4	0.3 - 2.0
Mystic River Estuary	4 - 12	0.1 - 0.3	0.4 - 4.0
Lower Charles River Basin	14 - 20	0.7 - 0.8	10 - 15
Charles River above Watertown Dam	0.3 - 12	0.1 - 0.7	0.02 - 9
Neponset River Estuary	5	0.2	1.0
Lynn-Saugus Estuary ¹	0.7 - 10	0.1 - 3.6	0.04 - 30

¹Cochrane and Gregory (1970)

Toxic Metals

Freshwater sediments in the metropolitan area which have been analyzed for toxic metal content include: The Charles River (Massachusetts Division of Water Pollution Control, 1974). Back Bay Fens (Charles E. Maguire, inc. 1973) and the North River (Massachusetts, Division of Water Pollution Control, 1973). Considerable attention has been given to marine and estuarine waters (Gilbert et al., 1972; White, 1972; Massachusetts Division of Water Pollution Control, 1973). A compilation of the results of the surveys, cited above, together with additional trace metal data on the Mystic River Estuary (Marine Environmental Services, 1973) is given in Table 9. High metal content is closely associated with high organic content (White, 1972). Zinc, in particular, accumulates in anaerobic polluted sediments; chromium, on the other hand, is readily transported away from polluted sediments to concentrate in planktonic organisms (Phelps et al., 1973). Sediment content of lead, nickel and zinc progressively diminishes from the highest recorded levels at the mouth of the Mystic River to the lowest seaward and southward of the Outer Harbor.

North River freshwater sediments are generally "cleaner" with respect to toxic metal concentrations than much of the estuarine portions of area waterways; the estuaries, where waters of vastly differing chemical nature meet, appear to function as heavy metal "sinks". Standards for maximum acceptable levels of toxic metals in sediments have been formulated by the EPA with regard to dredge spoil disposal.

BIOTA

In response to pollution, certain organisms are either excluded or are given a competitive advantage based on their tolerances to the various materials present. Aquatic organisms sensitive to pollution include caddisflies (*Trichoptera*), mayflies (*Ephemeroptera*) and game fish; pollution tolerant freshwater organisms include carp (*Cyprinus carpio*),, midge larvae (*Diptera*) and certain algae. Marine organisms are generally sensitive, but such forms as the green alga, *Ulva lactuca*, the polychaete worm, *Capitella capitata*, and the killifish, *Fundulus heteroclitus*, are pollution tolerant. When a polluted condition exists its effects are generally evident throughout the entire community (e.g. finfish, benthic invertebrates and plankton; Figure 16).

Productivity

Measurements of chlorophyll a content have recently come into vogue as an indication of primary productivity. The first use of this parameter in the Boston area was during the New England Aquarium water quality survey in 1970-1972. Since then, state

TABLE 9. MAXIMUM-MINIMUM SEDIMENT CONCENTRATIONS OF TOXIC METALS (ppm, dry wt.)
FOR SELECTED WATERWAYS OF THE EASTERN MASSACHUSETTS METROPOLITON AREA

LOCATION	CADMIUM	CHROMIUM	COPPER	LEAD	MERCURY	NICKEL	ZINC
Boston Inner Harbor	1 3-21	46-480	80-1300	100-850	0.7-30	20-250	140-3400
Boston Outer Harbor	0.1-15	7.1-430	4-430	14-430	0.02-6.7	5.2-87	29-650
Mystic River Estuary	0.3-10	8.6-410	36-1600	30-2000	0.4-23	19-540	110-7200
Neponset River Estuary	0.8-9.3	38-200	43-270	68-1000	0.1-4.0	15-38	90-570
Charles River	0.1-1.2	2.9-15	7.1-46	13-370	<0.01-0.55	2.8-12	12-120
North River	0.0-5.4	6.2-360	1.8-640	2.0-300	0.04-5.5	2.3-32	9-980

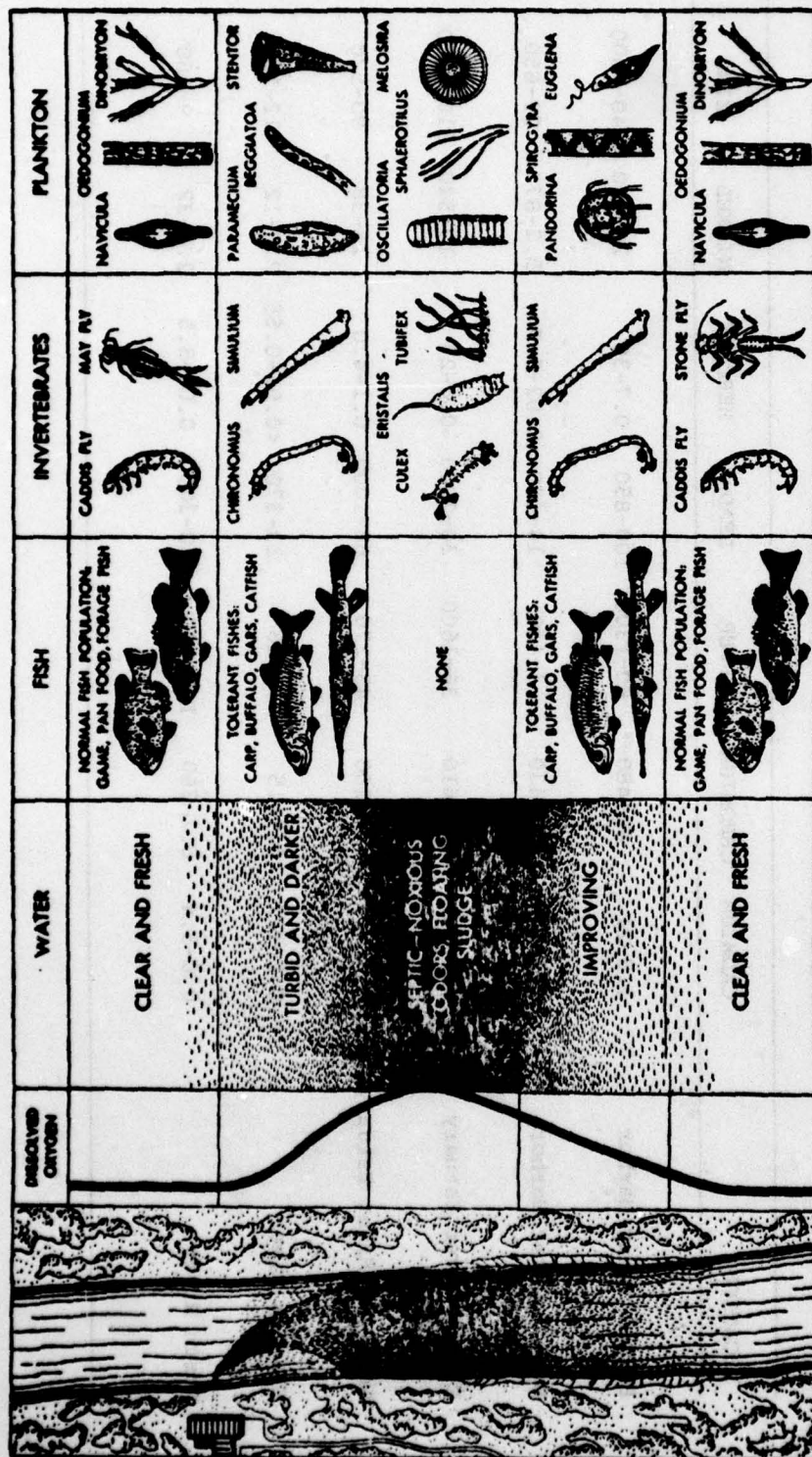


Figure 16. Pollution of a stream with untreated sewage and the subsequent recovery as reflected in changes in the biotic community. As the oxygen dissolved in the water decreases (curve to the left), fishes disappear and only organisms able to obtain oxygen from the surface (as in Culex mosquito larvae) or those which are tolerant of low oxygen concentration are found in zone of maximum organic decomposition. When bacteria have reduced all of the discharged material the stream returns to normal. (After Eliassen, Scientific American, Vol. 186, No. 3, March, 1952).

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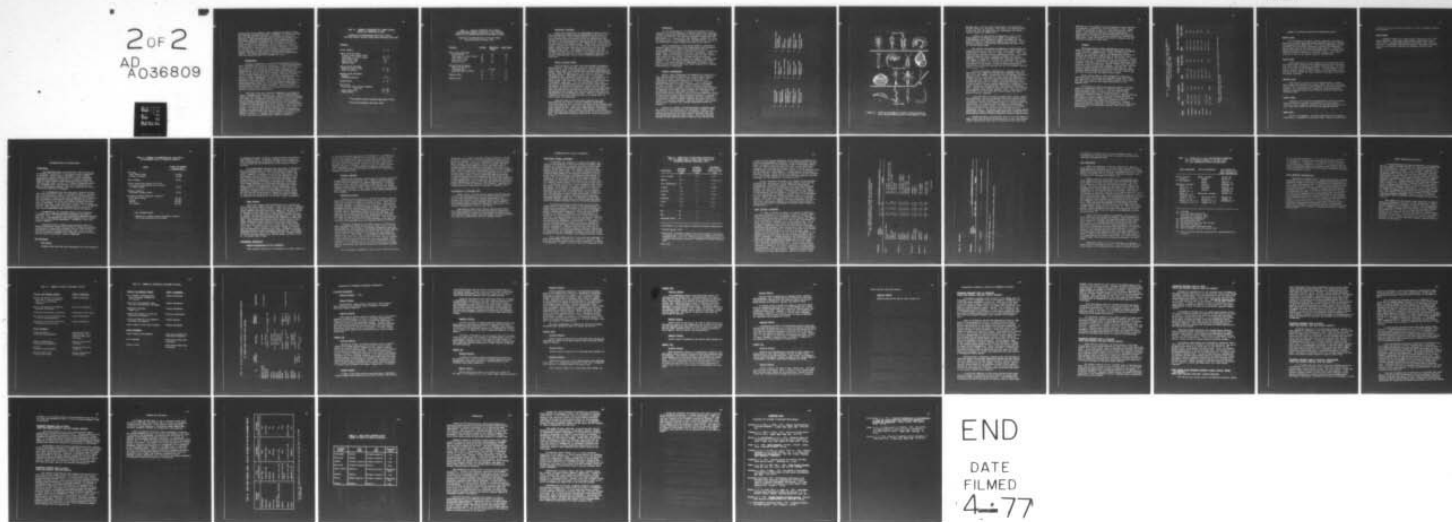
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surveys (1973) on the Charles, Mystic, Neponset and Ipswich Rivers have reported chlorophyll a values. From 1971 on, the state surveys have also employed the light-dark bottle method of determining production. Both Marine Environmental Services and Chesmore et al, 1973 report values for chlorophyll a in their respective study areas. A compilation of available data on summer chlorophyll a concentrations in the metropolitan area is presented in Table 10. Values in excess of 50 micrograms per liter (parts per billion) are indicative of "excessive algal growths" (Jaworski et al, 1972). In 1971 and 1972, the principal Boston Harbor phytoplankton bloom occurred from April to May, judging from New England Aquarium studies. The highest chlorophyll a concentration reported during that time period was about 46 micrograms per liter.

Phytoplankton

Planktonic communities in freely moving streams are usually poorly developed; few forms are indigenous. Standing waters upstream are a principal source of river phytoplankton; other plant forms in river plankton (e.g. filamentous green algae, *Spirogyra* spp. and *Oedogonium* spp, and the diatoms *Navicula* spp. and *Melosira* spp., Figure 15) are scoured from stream bottoms. Table 11 shows the relative mainstream abundance of three principal freshwater plankton groups: diatoms (*Chrysophyceae*), green algae (*Chlorophyceae*), and blue-green algae (*Cyanophyta*). While not true indicators of pollution, blue-green algae often thrive under such conditions (cf. *Oscillatoria* spp, Figure 16). Certain blue-green algae produce objectionable odors; most can fix nitrogen from the atmosphere (an advantage during summer nitrate shortages). Division of Water Pollution Control river studies do not include observations on the species of phytoplankton encountered.

Blue green algae are relatively unimportant in open marine waters. Diatoms are the dominant form. The New England Aquarium study lists the diatoms: *Coscinodiscus centralis*, *Nitzschia seriata*, *Chaetoceros* spp., *Skeletonema costatum* and *Thalassiosira nordenskiöldii* as the most frequently encountered species in Boston Harbor. Studies by Marine Environmental Services (1972) list approximately 40 species of phytoplankton which were collected in the Mystic River estuary. Eighteen of these species were diatoms. Other predominant groups in the estuary were the dinoflagellates and green algae. *Euglena*, an organism which indicates the presence of decomposition products in marine waters, was present in many of the Mystic River estuary collections. A summary of preliminary evaluations by Dr. H.F. Mulligan is contained under "studies in progress".

TABLE 10. SUMMARY OF REPRESENTATIVE SUMMER SURFACE
VALUES FOR CHLOROPHYLL A (ppb)

(Compiled From Massachusetts Division Of Water
Pollution Control Surveys Except Where Otherwise Indicated)

Location

Boston Harbor ¹	1 - 27
Mystic River Watershed	
Estuary (below Earhart Dam) ²	1 - 9
Mainstream (to Mystic Lakes)	29 - 92
Lower Mystic Lake	25
Upper Mystic Lake	24
Aberjona River	1 - 7
Charles River Watershed	
Watertown Dam to Dover	61 - 92
Dover to Milford	2 - 29
Neponset River Watershed	
Estuary	3
Freshwater portion	3 - 19
Ipswich River	0 - 17
North River	
Mainstream (below Norwell-Pembroke turn in)	2 - 27
Indian Head River	98 - 442
French Stream	0 - 4

¹ New England Aquarium Research Department (1973)

² Marine Environmental Services (1973)

TABLE 11. RELATIVE PROPORTION (%) OF MAJOR
PHYTOPLANKTONIC GROUPS IN JUNE-JULY, 1973, IN FRESH
WATERS OF THE EASTERN MASSACHUSETTS METROPOLITAN AREA

(Compiled From Massachusetts Division Of Water
Pollution Control Surveys, 1973)

<u>Location</u>	<u>Diatoms</u>	<u>Blue-Green Algae</u>	<u>Green Algae</u>
Mystic River Watershed			
Alewife Brook	2	68	30
Mainstream (to Mystic Lakes)	68	12	19
Lower Mystic Lake	98	0	1
Upper Mystic Lake	83	0	17
Aberjona River	13	55	31
Charles River Watershed			
Charles River Dam to Watertown Dam		no data	
Watertown Dam to Milford	24	15	60
Neponset River	15	72	13
Ipswich River	57	0	43

Macroalgae (Seaweeds)

Check lists contained in the Massachusetts Marine Fisheries Service studies of marine resources (Monograph Series, Nos. 2,5, 10,11 and 14) show a total of approximately 56 species of macroalgae existing along the seacoast, within the metropolitan area. Included in this group are such forms as sea lettuce (*Ulva lactuca*) and its allies (*Enteromorpha* spp. and *Monostroma* spp.) which thrive in waters polluted by domestic sewage. These algae, chiefly the sea lettuce, achieve their notoriety from the odor created by decaying fronds, which have been torn loose by waves and cast upon the beaches (Sawyer, 1965). The commercially valuable Irish moss (*Chondrus crispus*) is also abundant in the metropolitan area, as are many other desirable or, at least non-nuisance seaweeds, such as Kelp (*Laminaria* spp.) and rock weed (*Ascophyllum* spp. and *Fucus* spp.).

Aquatic Vascular Plants

Three principal life modes have been adopted by freshwater aquatic plants. The first mode, emergence, has been adopted by such plants as water lilies (*Nympha* spp.), cattail (*Typha* spp.) and rushes (*Juncus* spp.) which are rooted in the substrata and support foliage, seeds, and mature fruits a few inches to several feet above the water surface. Non-emergent species such as pond weeds (*Potamogeton* spp., *Elodea* spp. and *Najas* spp.) are attached to or rooted in the substrata, but uppermost parts rarely break the water surface. The third mode, free floating, includes such forms as duckweeds (*Lemna* spp.). On river mainstreams these plants thrive only in sheltered bends and close to shore, where currents and effects of erosion are diminished. Aquatic vascular plant inventories contained in two reports (Cassidy, 1971, on Upper Mystic Lake, and Jason Cortel and Associates on the Fowl Meadow Marsh of the Neponset River) suggest that the plant genera cited above are representative of the metropolitan area. Details of abundance and diversity of fresh water aquatic plants in the Boston area, in recent years, are unavailable.

Vascular plants of the salt marsh community have been inventoried by the Division of Marine Fisheries (Monographs). Cord grass (*Spartina* spp.) is by far the dominant form throughout most of the intertidal zone. Other salt marsh zones are dominated by eel grass (*Zostera marina*), black grass (*Juncus gerardi*) and widgeon grass (*Ruppia* spp.). Until recently, salt marshes in the Boston Harbor area have been subjected to destruction by land fill encroachment. The remaining few hundred acres are now under the protection of law.

Zooplankton

As with phytoplankton, the quality and quantity of river zooplankton is heavily dependent on upstream and bottom conditions. Division of Water Pollution Control survey reports list two groups, protozoa and rotifera. The protozoan category is subdivided into Mastigophora (e.g. *Euglena* spp.) and Infusoria (meaning all other protozoan groups, e.g. *Paramecium* spp. and *Stentor* spp., Figure 16). No information on genera or species is given in the reports.

Marine zooplankton of Inner Boston Harbor is dominated by copepods, particularly those of the genus *Acartia* and *Eurytemora*. In all, copepods of 13 species were identified by Marine Environmental Services (1972) in Mystic River estuary. Cladocerans (water fleas), coelenterates (jelly fish), chaetognaths (arrow worms), along with the pelagic larvae of these and other invertebrate groups are also listed. Although the marine plankton community may be somewhat depressed, with respect to abundance and diversity (due to the heavy discharge of pollutants into Boston Harbor), it is rarely possible to demonstrate an impact, since quick recovery and recruitment from "clean" sources is an inherent characteristic of this group.

Benthic Invertebrates

Benthic faunal assemblages are probably more indicative of long term environmental conditions in a body of water than any other form of biota. Because of their sessile habit, these organisms are particularly important in evaluating local environmental conditions (microhabitats). Some of the bottom dwelling organisms of the lentic (flowing water) environment are shown in Figure 17. Under healthy conditions (good water quality) the benthic community contains an abundance and diversity of organisms; particularly expected under such conditions would be organisms such as those shown in Figure 17, a through d. In places where organic loading is high, the benthic population shifts to more tolerant forms, like those shown in Figure 17, e through l. In waters with excessive organic pollution the total numbers of "intermediate" species is greatly reduced; such forms as shown in Figure 17, m through p dominate. Even the "tolerant forms" cannot survive where toxicants (e.g. heavily chlorinated sewage) are produced.

Results of a survey of freshwater benthic organisms along the course of the Charles River are tabulated in Stewart (1968). Five of the 17 collecting stations (29 percent) contained substantial quantities of pollution sensitive organisms (more than one hundred individuals per square foot). All of the stations containing these sensitive forms in quantity were upstream from

- | | | |
|---|-------------------------------------|---|
| A. Stonefly nymph
(Plecoptera) | F. Scud (Amphipoda) | L. Bloodworm or midge
fly larvae
(Tendipedidae) |
| B. Mayfly naiad
(Ephemeroptera) | G. Aquatic sowbug
(Isopoda) | M. Leech
(Hirudinea) |
| C. Hellgrammite or
Dobsonfly larvae
(Corydoridae) | H. Snail (Gastropoda) | N. Sludgeworm
(Tubificidae) |
| D. Caddisfly larvae
(Trichoptera) | I. Fingernail Clam
(Sphaeriidae) | O. Sewage Fly larvae
(Psychoda) |
| E. Black fly larvae
(Simuliidae) | J. Damselfly nymph
(Zygoptera) | P. Rat-tailed maggot
(Eristalis) |
| | K. Dragonfly nymph
(Anisoptera) | |

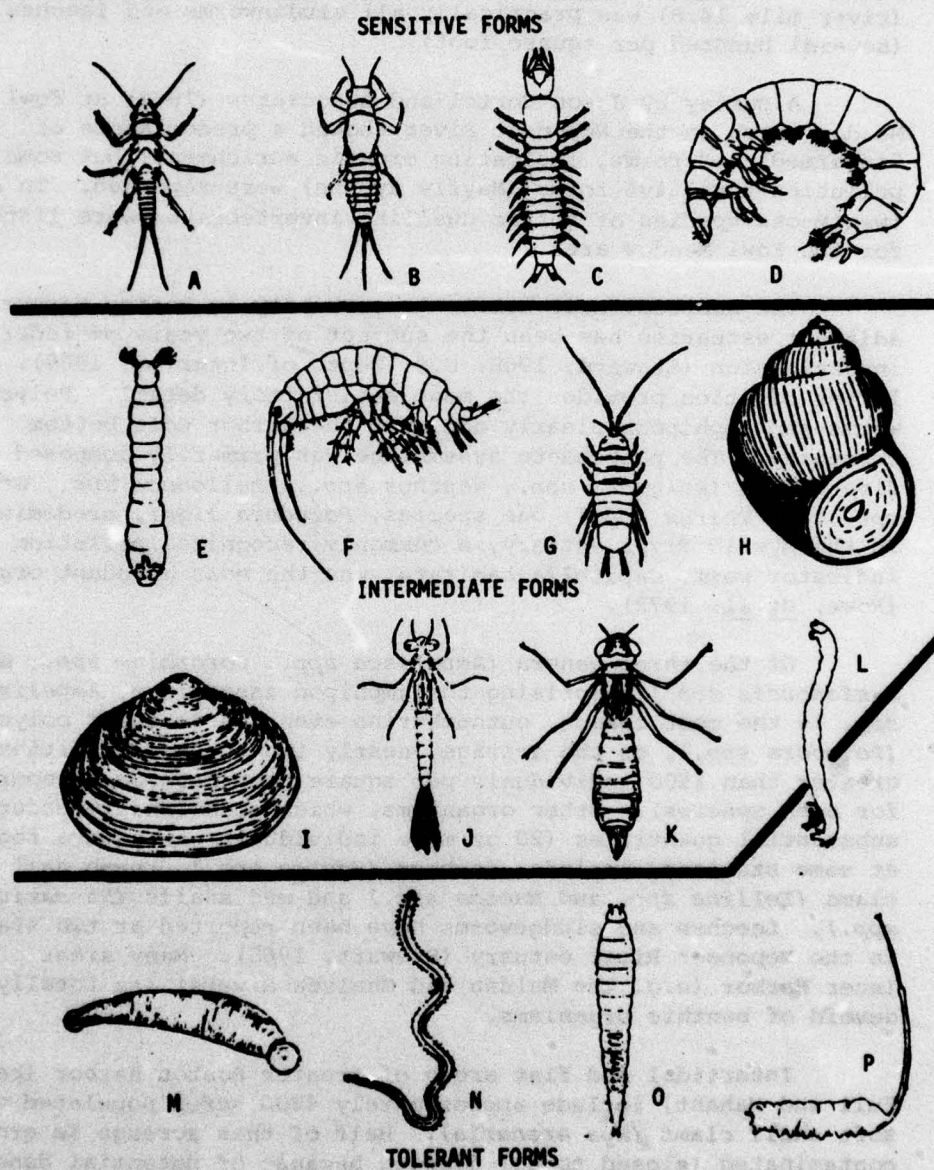


Figure 17. Pictorial arrangement of benthic organisms based on their relative sensitivities to environmental stress.

Waltham, Mass. The two collecting stations in the Lower Basin yielded virtually no organisms. The yield of the Waltham station (river mile 14.8) was practically all sludgeworms and leeches (several hundred per square foot).

A survey by Jason Cortel and Associates (1972) at Fowl Meadow Marsh on the Neponset River showed a predominance of "intermediate" forms, indicating organic enrichment; but some pollution sensitive forms (Mayfly nymphs) were reported. In all, twenty-one species of bottom dwelling invertebrates were listed for the Fowl Meadow area.

The subtidal soft substrate community in Boston Harbor and adjacent estuaries has been the subject of two years of federal investigation (Steward, 1968; U.S. Dept. of Interior, 1969). The latter citation provides the most satisfactory detail. Polychaete worms and amphipods clearly dominate the harbor soft bottom community. The polychaete assemblage was primarily composed of five genera (*Polydora* spp., *Nephtys* spp., *Phyllodoce* spp., *Eteone* spp., and *Tharyx* spp.); one species, *Polydora ligni*, predominated. In the Mystic River estuary, a commonly recognized pollution indicator worm, *Capitella capitata*, was the most abundant organism (Rowe, et al. 1972).

Of the three genera (*Ampelisca* spp., *Corophium* spp., and *Lysianopsis* spp.) comprising the amphipod assemblage, *Ampelisca* spp. is the most common, outnumbering even the dominant polychaete (*Polydora* spp.), on the average, nearly two to one (densities greater than 1500 individuals per square foot have been reported for both species). Other organisms, which occasionally occur in substantial quantities (20 or more individuals per square foot) at some stations, include: sowbugs (*Edotea* spp.), thumb nail sized clams (*Tellina* spp. and *Macoma* spp.) and mud snails (*Nassarius* spp.). Leeches and sludgeworms have been reported at two stations in the Neponset River estuary (Stewart, 1968). Many areas of the Inner Harbor (e.g. the Malden and Chelsea Rivers) are totally devoid of benthic organisms.

Intertidal mud flat areas of greater Boston Harbor (between Hull and Nahant) include approximately 4200 acres populated with soft shell clams (*Mya arenaria*). Half of this acreage is grossly contaminated (closed to all digging because of potential danger to human health); the remaining half is moderately contaminated (open to licensed master diggers, the harvest must be processed for purification through the shell fish treatment plant at Newburyport, Mass.). At present there is no area in greater Boston Harbor open to public digging without restriction (Iwanowicz, H.B., Massachusetts Division of Marine Fisheries, personal communication).

Besides bacterial contamination, there is also the danger to human health from shellfish biomagnification of toxic heavy metals. Coastal Massachusetts heavy metal concentration levels have been

reported for tissue samples from three species of shellfish which are important in human diets (Issac and Delaney, 1972). These values are reproduced in Table 12, along with reported "alert" levels. Alert levels are defined as levels which differ significantly from base line levels established from shellfish populations not influenced by possible heavy metal concentration; alert levels (Issac and Delaney are careful to explain) are not necessarily related to toxic levels.

Finfish

Mainstream waters of major metropolitan rivers are in general too warm to support a substantial population of salmonids (trout) during the summer months. During a finfish survey conducted in the summer of 1969 by the Massachusetts Division of Fisheries and Game, water temperatures as high as 82°F. were recorded on the Charles River and some of its tributaries. During the survey, a total of 29 species of fish were collected, of which pickerels (*Esox spp.*), white suckers (*Catostomus commersoni*), brown bullheads (*Ictalurus nebulosus*), sunfish (*Lepomis spp.*) and carp (*Cyprinus carpio*) were the most abundant. Of these fish, only the red fin and chain pickerels are considered game species. One tributary (Hopping Brook) contributed 20 brook trout and another (Seaverns Brook) yielded 245 brown trout; no native trout of any kind were collected from the Charles River itself.

Recent finfish data on other metropolitan watersheds is extremely scarce. The Cortel and Associates study (1972) lists four species of finfish (chain and redbfin pickerel, white sucker, and carp) taken from the Fowl Meadow Marsh region of the Neponset River.

The inventory of marine and estuarine finfish is far more complete; Massachusetts Division of Marine Fisheries, Marine Resources Studies (Nos. 2,5,10,11 & 14) list approximately thirty different species in the metropolitan area. Of the commercially exploited species, winter flounder (*Pseudopleuronectes americanus*) is the only remaining finfish in great abundance. Non-commercial finfish commonly reported in the tidal creeks and river mouths include eels (*Anquilla rostrata*), killifish (*Fundulus spp.*) and silversides (*Menidia menidia*). Blueback herring and alewives (*Alosa spp.*), and smelt (*Osmerus mordax*) were captured by Marine Environmental Services (1972) in the Mystic River estuary.

TABLE 12. CONCENTRATIONS OF HEAVY METALS IN SHELLFISH HARVESTED
IN MASSACHUSETTS COASTAL WATERS (ppm, WET WEIGHT)
(Issac and Delaney, 1972)

<u>Metal</u>	<u>Oyster (4 samples)</u>		<u>Quahog (18 samples)</u>		<u>Soft Shell Clam (30 samples)</u>	
	<u>Mean</u>	<u>Alert Level</u>	<u>Mean</u>	<u>Alert Level</u>	<u>Mean</u>	<u>Alert Level</u>
Cadmium	0.78 \pm 0.48	3.5	0.26 \pm 0.31	0.5	0.30 \pm 0.33	0.5
Chromium	0.08 \pm 0.13	2.0	1.2 \pm 0.89	1.0	1.96 \pm 0.77	5.0
Copper	1.31 \pm 0.92	175	7.2 \pm 4.3	10	28.8 \pm 18.5	25
Lead	0.29 \pm 0.13	2.0	1.9 \pm 1.2	4.0	5.45 \pm 8.09	5.0
Mercury ¹		0.2	0.30 \pm 0.21	0.2	0.31 \pm 1.06	0.2
Nickel	0.70 \pm 0.29		2.2 \pm 0.75		3.7 \pm 4.7	
Zinc	747 \pm 449	2000	29 \pm 11	65	34.3 \pm 20.7	30

1 Maximum acceptable concentration in any aquatic organism is a total body burden of 0.5 ppm (EPA, 1973)

SUMMARY OF EXISTING CONDITIONS BY HYDROLOGICAL REGION

CHARLES RIVER

The introduction of organic wastes, beginning at Milford has resulted in unstable dissolved oxygen conditions and highly variable water quality in the upper basin. The river is moderately polluted throughout its mid-section, although it receives few authorized wastes after entering the Metropolitan Sewer District. Conditions rapidly deteriorate as the river approaches Boston. From Watertown to Boston Harbor the Charles is no longer a river in the literal sense but a lake in the advance stages of eutrophication.

MYSTIC RIVER

Marked depression of algal productivity on the Aberjona River and Alewife Brook coupled with high ammonia and pH levels indicates high level flows of industrial discharges (theoretically, all wastes flow to the Deer Island treatment plant). A strong chemical (salt) barrier prevents renewal of bottom waters in the lower Mystic Lakes. The Mystic River (below the lakes) supports a depauperate population of aquatic organisms.

NEPONSET RIVER

Water Quality in this river has remained stable in recent years (moderately polluted with organic wastes, but with relatively little toxins of industrial origin compared to the Charles and Mystic systems). Low flows place this stream in a vulnerable category, especially upstream from the flow diversion from the Charles River via Mother Brook.

IPSWICH RIVER

Comparison of 1973 with 1968 Massachusetts Division of Water Pollution Control Data shows a deterioration in water quality (increased organic loading), especially in upstream portions of this river, once the cleanest of the five river systems discussed.

NORTH RIVER

As with the Neponset, low flows in portions of this stream system make it vulnerable to pollution loads. Excessive summer algal

productivity is one of several indicators of over enrichment (organics and nutrients).

BOSTON HARBOR

Industrial wastes (e.g. heavy metals) characterize the inner harbor sediments. Two large sewage treatment plants add a heavy organic load. Combined sewer overflows are another major source of pollution. Marine water and sediment quality, and species diversity improves with distance, eastward and southward, from the inner harbor.

RECOMMENDATIONS FOR FURTHER STUDY

INTRODUCTION

The requisite number of studies which could be conceived as necessary to provide all of the possibly useful information is unlimited. Certain gaps in knowledge, if left standing, would greatly restrict further efforts to evaluate wastewater management alternatives (including a "no action" alternative). Types of studies needed to more adequately establish base line conditions are listed in Table 13, in order of descending priority; estimated costs, also included, were established on the basis of professional judgment, and do not represent the result of detailed itemization of expenses.

It is recommended that even more public funds be utilized than those indicated in Table 13, provided the money is available, since the extra expense would be reflected in the generation of more qualitative scientific data and a broader base of information. The cost/benefits occasioned by increased funding levels (up to four times those levels cited) would greatly enhance our present state of knowledge. On the other hand, if less funds are made available than those levels indicated in Table 13, it is recommended that the study in question not be pursued at all, since the return from an underfunded study would not justify the expense.

Recommendations are discussed below in three categories: 1) studies which represent approaches different from studies previously cited, 2) studies which essentially supplement previous ones, and 3) recommendations concerning dissemination of information from studies already implemented. Categories 1 and 2 are listed in Table 13.

Procedures used for conducting and reporting results of future environmental studies should adhere to established national or preferably, international standards, such as those described in "Biological Field and Laboratory Methods" (EPA, 1973) or International Biological Programme (IBP) Handbooks, published by Blackwell Scientific Publications, Oxford & Edinburgh.

NEW APPROACHES

Dye Studies

Rhodamine dyes have been used successfully as tracer materials

TABLE 13. SUMMARY OF RECOMMENDED BASE LINE STUDIES
AND APPROXIMATE COSTS, BY ORDER OF PRIORITY

<u>STUDY</u>	<u>MINIMUM RECOMMENDED FUNDING LEVEL</u>
Dye Study	
Fresh Water Stream	\$ 10,000 ¹
Estuary of Coastal	30,000 ¹
Algal Bioassay	45,000
Finfish Tissue Toxic Materials Content	
Five major stream system, plus 47 miles of coastal waters	80,000
Sediment Chemistry	
Five major stream systems	75,000
Mathematical Model (physical, chemical) ²	
Fresh water stream	80,000
Estuary	240,000
Coastal	400,000
All systems	720,000

¹ per treatment plant

² adaptation of models already available, costs of
field data acquisition not included.

to determine the amount of natural mixing to dilute the effluents from treatment plants. Information provided by such studies relates the flushing rate of the body of water to the ultimate fate of the effluent and the concentration of the effluent in space and time.

In the development and design of a dye study, a fluorescent dye is discharged from a calibrated fluid metering pump at the proposed discharge location. The resulting plume is monitored using a commercial fluorometer to detect the fluorescence. The fluorometers used are especially modified and adapted for full-flow continuous sampling from both stationary and moving craft. By monitoring the concentration of the dye in the water it is possible to determine the degree of dilution due to tidal and other mixing processes at a given place and time in the tidal cycle. Isopleths of dilution may then be constructed to allow determination of the concentration of any constituent of the effluent at various locations at any phase in the tidal cycle. Additional information can be obtained from the "decay" of the dye after the dye metering pump is turned off since the amount of time required for the dye to be removed by natural processes is related to the flushing rate of the body of water in question.

Algal Bioassay

Some of the streams under consideration (e.g. the Aberjona River) carry heavy loads of toxicants. Since the streams in question may also carry heavy nutrient loads, to which even the more advanced sewage treatment processes contribute, removal of toxicants (as may be required by strict pollution control standards) could lead to an increase in algal productivity, rather than a decrease as would be desired. The specific requirements and responses of local algal populations are most properly addressed by conducting an algal bioassay. This interpretive technique would involve placing a water sample containing a known concentration of native algae into a series of flasks containing various nutrient media (some flasks will contain the suspect river water, others will be free of toxicants, etc.). After a period of incubation, changes in standing crop are determined by counting plant cells. Chlorophyll a determinations may also be used to determine standing crop. Conceivably, experiments of this nature could demonstrate that stringent removal of certain nutrients need only be required during a portion of the year to control algal blooms.

SUPPLEMENTAL INFORMATION

Tissue Concentrations of Toxic Materials

Toxic materials content in the biosphere is of major concern in

an area of heavy industrialization and urbanization. In addition to the shellfish analysis completed by the Division of Water Pollution Control (Isaac and Delaney, 1972), a survey should be made of all major food fish species (in both fresh and salt water) with respect to tissue content (body burden) of metallic elements (especially mercury, lead, zinc, cadmium, chromium, nickel and copper), halogenated hydrocarbons (e.g. polychlorinated biphenyls) and any other toxic substances which may, in future, be identified as potentially dangerous to human health.

Sediment Chemistry

Sediments are both major repositories and sensitive indicators of many water borne constituents (e.g. organics and heavy metals). Studies should be undertaken to improve understanding of sediment chemistry in the five major freshwater stream systems. At present there are limited data on organic content of Charles River bottom sediments, but knowledge of toxic metal concentrations is incomplete even for this river which is the largest of the eastern metropolitan river systems.

Mathematical Models

Increasing use has been made of mathematical models (usually executed in the form of computer programs) as a decision making tool within the analytical framework of systems analysis. Water quality management problems are among those for which models have been proposed and designed. The systems analysis approach to water quality management has been thoroughly reviewed by Thomann (1972). Specific problems relating to estuary modeling are discussed by Dailey and Harleman (1972). Mathematical models can be very expensive (c.f. Table 13) and therefore are most efficiently utilized where small modifications of a generalized system (represented by the model) are likely to produce large improvements or gains. Thus the choice of a model and its complexity is as much dependent on the need and intuition of the designer as on the financial resources available.

A principal advantage of the models approach is flexibility. Models are generally capable of simulating a wide variety of prototype conditions. With respect to wastewater management, these conditions might be the distribution of pollutants from various disposal points, given various freshwater flow rates, and (in estuary and coastal regions) tidal stages. As an example of model predictive capabilities, one might be able to show benefits achieved by intermittent rather than continuous injection of wastes near the boundary between estuarine and ocean waters (cf. Dailey and Harleman, 1972). Ultimately it is expected that the mathematical model will play an important role in economic and political decisions which will determine the distribution and level of treatment in wastewater treatment plants.

For the present, mathematical models function best as an engin-

engineering tool, to be used to determine relative effects of various wastewater alternatives on physical and chemical aspects of the aquatic environment. Due to the complexity of natural environmental systems, and the present level of technology, approximations and simplifying assumptions cannot be avoided, but an engineering model need simulate the processes which occur in a natural system only to the extent required for the level of analysis. Thus, an engineer may justifiably choose a few environmental criteria (such as salinity, dissolved oxygen and B.O.D.), as a decision making index to reflect underlying complex processes, as long as reliance on these parameters does not result in misleading interpretations (it is here that discourse with biologists is most appropriate). To the ecologist, the predictive capacity of present mathematical models is far from satisfying; as far as the prediction of biological responses are concerned, "quantification of many processes is presently not possible" (Lombardo, 1973).

DISSEMINATION OF AVAILABLE DATA

Recent results of water quality surveys have now been published by the Massachusetts Division of Water Pollution Control for all five major fresh water systems considered in the present study; however, the microscope analysis data (plankton) would be more useful if more taxonomic detail were presented and organism population densities reported in metric units (e.g. number of organisms per liter of cubic meter).

Approximately weekly water quality and sanitary surveys are usually conducted by the Metropolitan District Commission (MDC), particularly on portions of the Charles and Mystic Rivers. Plans should be made to make these data public in an easily assimilable form (e.g. periodically issuing a summary booklet).

ASSUMPTIONS AND CRITICAL INFORMATION

FRESH WATER (INLAND) DISCHARGES

To determine the response of a fresh water aquatic ecosystem to the discharge of advanced wastewater treatment (AWT) effluent it is necessary to consider the interactions between quality and quantity of discharged effluent and quality and quantity of the stream water. For example, should the oxygen demand (organic matter load) of the river be greater than the projected oxygen demand of the wastewater effluent (as would be the case in many portions of metropolitan area streams, cf. Tables 3 and 14), the stream would benefit from discharge of wastewater. On the negative side, if the stream in question also contained a high level of phytotoxins (e.g. residual chlorine, ammonia, certain metallic ions such as mercury and nickel etc.), the removal or dilution of these substances might encourage nuisance algal growths, and, hence, ultimately elevate oxygen demand. As determined by comparing Tables 5, 6, and 14, concentrations of nitrogen and phosphorous (the two elements which play the major role in eutrophication) would probably be more than sufficient to permit dense plant growth (in the absence of phytotoxins), even at advanced levels of proposed wastewater treatment (Table 14). In addition to river water and sewage effluent sources there are unknown additional quantities of nutrients presently stored in the bottom sediments.

The quantity and kind of phytotoxins (as well as substances toxic to other forms of life) in the proposed AWT discharge are not known with the degree of certainty necessary to predict organism responses. To the extent that the treatment process includes biotic components, toxins can generally be assumed to be present in relatively low concentrations, if present at all, and therefore would exert little discernible influence. One group of phytotoxins, the chloramines, could become a potential component of the discharged effluent, as it is intended that the wastewater, containing up to 5 ppm ammonia, will be chlorinated after treatment (alternative methods of controlling human pathogenic organisms would be more environmentally acceptable). However, since the EPA (1973) has, at present, extremely restrictive standards regarding discharge of residual chlorine into freshwater streams (0.5 ppb), the problem of eutrophication may overshadow the problem of toxicity in the management of effluent discharges into metropolitan area streams.

Until algal assays and dye studies have been performed, no detailed assessment of local biotic response is possible (even after the necessary studies are performed, assessment is a matter of probability). However, a general idea of the magnitude of the

TABLE 14. COMPOSITION OF APPROXIMATE CONCENTRATION LEVELS OF KNOWN SEWAGE EFFLUENT CONSTITUENTS WITH RECOMMENDED MAXIMUM PERMISSIBLE LIMITS

CONSTITUENT	SECONDARY EFFLUENT ¹ (ppm)	ADVANCED WASTEWATER TREATMENT ¹ (ppm)	RECOMMENDED UPPER LIMIT IN RECEIVING WATER (ppm)
Total nitrogen	20	20	0.3 ²
Ammonia	9.8	< 1	0.02, 0.4 ^{3,4}
Total phosphorous	10	< 1	0.1 ²
Cadmium	0.1	?	0.004 ⁴
Chromium	0.2	?	0.1 ⁴
Copper	0.1	?	0.05 ⁴
Manganese	0.2	?	0.1 ⁴
Nickel	0.2	?	0.1 ⁴
Zinc	0.2	?	0.1 ⁴
BOD	30	5	
COD	70	?	
Suspended solids	30	5	

¹ Dave Kenyon, U.S. Army Corps of Engineers, personal communication

² Jaworski *et al.*, 1972

³ Lower value, freshwater; higher value, marine waters; values apply to alkaline (pH > 7.0) conditions only; in the absence of alkaline discharges (pH 7.5 to 9.0). Ammonia toxicity would probably not be a serious environmental problem in freshwaters of eastern Massachusetts.

⁴ EPA, 1973

influence of the proposed discharges may be gained from hydrological considerations presented in Table 15. It may be determined from this table, for example, that the treatment plants at Framingham (Sudbury River) and Woburn (Aberjona River) will exert a major hydrological influence. The influence of treatment plants at Concord (on the Concord River) and Canton North (under concept 2, on the Neponset River) will be relatively slight, however. Further comments with regard to potential negative, neutral and positive impacts of each five concepts (in so far as these impacts can be discerned using presently available knowledge) will be offered in a following section.

Siting a wastewater treatment plant inland from the seawater intrusion zone, and close to a water supply system, would have the advantage that the effluent (further treated to ensure public acceptability) could be utilized should a critical water shortage develop. The water from the treatment plant might also be made suitable for industrial purposes. Reasoning follows that, because of the freshwater recovery potential, wastewater treatment plants should be constructed in strategic locations (such as in Framingham, near the Sudbury Reservoir) despite probable injury to river ecosystems. This logic would be stronger if it were also considered feasible to recover, for example, nitrogenous compounds (for use in fertilizer) and thereby safeguard the river ecosystem from such negative consequences as nitrogenous biochemical oxygen demand and eutrophication.

OCEAN (COASTAL) DISCHARGES

In order to predict the impact of a coastal or estuarine wastewater discharge (at the secondary level of treatment) rather precise knowledge of local hydrographic conditions is required. A particularly undesirable situation would be created, for example, by the impoundment of effluent in an area of poor circulation, as might occur during a flooding tide or high onshore wind. It can be seen from Table 14 that, within the hypothetical area of impoundment, acceptable stream levels of both nutrients and toxic metals would be exceeded. Toxic effects may or may not neutralize the growth-stimulating effect of available nutrients; the ultimate response can only be gauged from results of an algal assay. Another serious problem which may be caused by impoundment is biomagnification of toxic metals at various trophic levels in the aquatic ecosystem. A related problem is the dissemination of coherent water masses containing secondary level pollutants over a wide area, involving many marine communities (e.g. salt marsh, rocky intertidal, shellfish beds, etc). In all events, determining the distribution and dilution of effluent discharge with reasonable certainty is of critical importance in sewage outfall site evaluation. This can be best accomplished by conducting dye studies of the areas under question. Whenever a sewage outfall is located in or near marine waters, special care must be taken

TABLE 15. POTENTIAL INFLUENCE OF AVERAGE DAILY DISCHARGE RATES¹
OVER RIVER FLOW RATES DURING 7 DAY, 10 YEAR LOW FLOW²

WATERSHED	SEWAGE TREATMENT PLANT	RATIO OF WASTEWATER FLOW TO RIVER FLOW				REMARKS
		2000	2020	2050		
SUASCO	Marlborough Wstly	9.3	17	25		all concepts
	Hudson	2.6	---	---		all concepts, discontinued by 2020
	Stow	---	3.1	5.2		all concepts, not operating in 2000
	Framingham	24	31	38		concepts 2 and 4 only
	Sudbury	2.2	4.8	5.9		all concepts
	Concord	0.6	1.1	1.6		all concepts
Charles R.	Milford	7.4	9.2	9.8		all concepts, except 3
	Medway	3.1	6.2	8.8		all concepts, except 3
	Medfield	0.9	1.7	2.5		all concepts, except 3
	Dedham	3.8	4.8	4.9		concept 2 only
	Dedham	2.8	3.6	3.8		concept 4 only
	Watertown	6.3	7.2	7.2		concepts 2 and 4 only
Neponset R.	Canton	3.9	5.1	5.6		concept 4
	Canton North	0.7	0.9	1.0		concept 2
	Canton South	6.8	8.6	9.4		concept 2
Ipswich R.	Middleton	4.0	7.2	10		all concepts
	Hamilton	1.2	5.4	4.4		all concepts
Mystic R.	Woburn	≈100	≈100	≈100		concept 4 only
	Medford	17	19	18		concept 4 only

Continued

TABLE 15. CONTINUED

WATERSHED	SEWAGE TREATMENT PLANT	RATIO OF WASTEWATER FLOW TO RIVER FLOW			REMARKS
		2000	2020	2050	
North R.	Rockland	---	---	---	low flow data not available

1 From Metcalf and Eddy, Engineers, 1974

2 Estimated, M.S. Slotkin Army Corps of Engineers, personal communication

to remove the residual chlorine from the effluent before it is discharged into the receiving waters to protect sensitive marine organisms from potential harm.

LAND APPLICATION

Base line terrestrial ecological conditions in eastern Massachusetts and responses of the terrestrial ecosystem to wastewater application have been dealt with in great detail in a separate report to the Army Corps of Engineers (Normandeau Associates, 1974). Briefly, two methods of land treatment have been proposed: spray irrigation (SI) and rapid infiltration (RI).

Spray irrigation can be effective in removing most wastewater constituents which would have a potential negative impact on an aquatic ecosystem; the constituents are held in the soil, or, in the case of nutrients and some heavy metals, taken up by plants. Only when the plants are harvested, are the stored constituents truly removed from the application site, otherwise the substances will be recycled within the ecosystem. Some constituents, such as lead, may accumulate on the application site within a few decades, necessitating eventual abandonment of the site, and a search for additional land. Land available for wastewater application is in critically short supply in the metropolitan area; this fact, more than any other, restricts the feasibility of SI as a method of accommodating the bulk of wastewater generated in the study area. Other important disadvantages are the extreme stoniness of Massachusetts soils, and the paucity of soil types with highly suitable edaphic characteristics (cf. Table 16). Soil limitations, however, can be overcome by sufficient site preparation (to permit the use of some of the soil types in the moderately suitable category, Table 16).

Rapid infiltration requires considerably less acreage than SI to dispose of equal amounts of effluent. Many Massachusetts soils (i.e. those developed from deep sand deposits) are suitable for RI (Table 16). Because wastewater percolates rapidly downward, there is a considerable degree of uncertainty as to the renovation potential of the deep, rapidly permeable, sandy soils used for RI; experiments involving test applications of wastewater by the RI technique have yielded variable results. At least a portion of the nutrient and heavy metal constituents appear to be filtered out as the wastewater passes the upper few inches of topsoil. Removal of nitrogen, particularly, can be facilitated in RI applications when certain grass crops (e.g. reed canary and alfalfa brome), which have high nitrogen requirements, are cultivated.

Regardless of which of the two techniques are employed, dilution of the wastewater percolate by the receiving ground water plays a major role in determining the resulting chemical quality

TABLE 16. SUITABILITY OF SOILS FOR WASTEWATER RENOVATION
(SOIL TYPES NAMED ACCORDING TO THE MOST RECENT
U.S. SOIL CONSERVATION SERVICE DESIGNATIONS)

SPRAY IRRIGATION	RAPID INFILTRATION	NOT SUITABLE FOR SPRAY IRRIGATION OR RAPID INFILTRATION
Highly suitable: Charlton *** Narragansett	Highly suitable: Agawam Carver Dukes	Au Gres (5) Hollis (6) Muck (5) Limerick (5)
Moderately suitable: Acton (1) Buxton (2) (3) Canton (1) Elmwood (2) (3) Essex (1) Ninigret (silty subsoil) (2) (4) Paxton (1) (4) Sutton (1) (2) (3) Winooski (1) (2) (3)	Enfield Hinckley Merrimack Windsor Moderately suitable: Deerfield (2) (3) Hadley (2) Ninigret (2) (3) Sudbury (2) (3)	Ridgebury (5) Saco (5) Saugatuck (8) Scarboro (5) Scituate (7) Swanton (5) Walpole (5) Whitman (5) Woodbridge (7)

-
- (1) Stoniness
 - (2) Saturated with water during late fall, early spring, heavy precipitation, flooding, etc.
 - (3) Seasonally high watertable
 - (4) Low infiltration rate
 - (5) Saturated with water for most of year
 - (6) Soil depth too shallow
 - (7) Conditions promote overland runoff
 - (8) Shallow hardpan, high infiltration rate

*** Certain critical details concerning soil characteristics not available.

of the recharged groundwater. SI is not feasible as a technique for disposal of wastewater when temperatures are below freezing (ice formation). Wastewater can be applied by the RI technique at subfreezing air temperatures; however, it is doubtful that any degree of renovation would be accomplished under these conditions, since neither plant uptake or denitrification (microbial) reactions would be expected to occur.

OTHER IMPORTANT CONSIDERATIONS

Wastewater management plans, as presently conceived, address themselves to only a portion of the complex problem pertaining to wastewater disposal in the Eastern Massachusetts Metropolitan Area. Unless such considerations as: 1) separation of storm drains from sewer systems (to eliminate the problem of sewage contaminating precipitation runoff); 2) disposal of sludges from the various treatment processes; and 3) detection and prevention of unauthorized discharges are dealt with in the overall plan, the meaningfulness of such impacts as are discussed below will be considerably lessened and resulting conditions will more closely resemble those described under the "no action" alternative, especially with respect to the central core of the Boston metropolitan area. Further, as long as the kinds of constituents typically found in wastewater are managed as unwanted materials to be discharged rather than resources to be recovered and used, negative ecological impacts accruing from wastewater discharges are bound to outweigh positive ones.

IMPACT ASSESSMENT METHODOLOGY

In the determination of impacts described in the following section, neither a systems approach nor other complex analyses of data were employed; in our opinion, the available data are far too limited for such treatment to be warranted. Subjective (professional) judgement was used in place of quantitative analysis. The approach was, however, quantitative to the extent that data demonstrating existing physical and chemical conditions (specifically Tables 4 through 9, and Figures 8 through 15) were visually compared to data on effluent constituents and relative volume (Tables 14 and 15). Organism responses were determined in general from a review of the scientific literature dealing with physiological tolerances and the effects of various pollutants on community structure (abundance and diversity). A list of criteria considered to be of critical importance is given in Tables 17 and 18, along with comments on the availability of pertinent information. The criteria listed were used to predict the impacts of a specific wastewater management concept (in all, six are discussed below) where the present state of knowledge was sufficient to do so.

With respect to each concept, three categories of probable impacts are designated: positive, neutral and negative. Table 19 rates each of the six concepts in order of their acceptability from the standpoint of environmental impacts, for each treatment plant. Coastal treatment plants (previously discussed) have not been rated since: 1) there is no change from one concept to another and 2) there are few facts upon which an accurate impact assessment may be based. Following positive, neutral, and negative assessment of each concept, the impacts of eight key wastewater treatment plants (on which differences between concepts focus) are evaluated in some detail.

TABLE 17. SUMMARY OF AQUATIC ASSESSMENT CRITERIA

PHYSICAL AND CHEMICAL EFFECTSSTATE OF KNOWLEDGE

Quality and quantity of chemicals
dissolved in receiving waters
(esp. N, P, and various
toxicants).

Largely determined

Quality and quantity of chemicals
dissolved in effluent

Partially determined

Dispersion and dilution of effluent

Undetermined (dye study)

Net quantity of water diverted into
or out of area watersheds

Largely determined

Hydrological influence of effluent
discharge over river flow

Largely determined

BIOTIC RESPONSES

Primary producers
(diversity and abundance)

Undetermined locally
(algal assay), but
generally known from
literature

Benthic invertebrates
(diversity and abundance)

Generally known from
literature

Finfish
(diversity and abundance)

Generally known from
literature

Toxicant body burden
(fin and shell fish)

Largely undetermined
(tissue assays)

TABLE 18. SUMMARY OF TERRESTRIAL ASSESSMENT CRITERIA

<u>PHYSICAL AND CHEMICAL EFFECTS</u>	<u>STATE OF KNOWLEDGE</u>
Soil (edaphic) characteristics (esp. stoniness, permeability and texture)	Largely determined
Water table relationships (esp. cyclical fluctuations in WT depth)	Largely determined
Topography (drainage, slope, etc.)	Largely determined
Quality and quantity of chemicals dissolved in effluent	Partially determined
Quality and quantity of groundwater available for dilution	Largely unknown
Annual number of days below freezing	Largely determined
<u>BIOTIC RESPONSES</u>	
Plant diversity and abundance	Some results known from scientific literature
Soil Organisms	Some results known from literature
Higher animals	Some results known from literature

TABLE 19. RATING OF ENVIRONMENTAL ACCEPTABILITY OF WASTEWATER MANAGEMENT CONCEPTS
BY PLANNED SEWAGE TREATMENT PLANT LOCATION

STP	HIGHLY ACCEPTABLE	ACCEPTABLE	MARGINALLY ACCEPTABLE	UNACCEPTABLE
Marlboro Wstly		All Concepts		
Marlboro Estly		All Concepts		All Concepts
Hudson/Stow		Concepts 1, 3, 5 and 6	Concepts 2 and 4	
Framingham				
Sudbury		All Concepts		
Concord		All Concepts		
Milford		All concepts, except 3	Concept 3	
Medway		All Concepts		
Medfield		All Concepts		
Wellesley		Concept 6		
Dedham		Concepts 1, 3, and 6	Concepts 2, 4 and 5	Concepts 2 and 4
Watertown		Concepts 1, 3, and 6	Concept 5	
Canton		Concepts 1 and 3	Concepts 2, 4, 5, and 6	
Middleton		All Concepts		
Hamilton		All Concepts		
Woburn	Concepts 4 and 6	Concepts 1, 2 and 3	Concept 5	
Medford	Concept 4	Concepts 1, 2, 3, and 6	Concept 5	

EVALUATION OF WASTEWATER MANAGEMENT ALTERNATIVES

NO ACTION ALTERNATIVE

Positive Effects -- None.

Neutral Effects

Boston Harbor, Lower Charles River Basin, and the Mystic River watershed would probably remain essentially unchanged from their present condition.

Negative Effects

Water quality and the quality of aquatic life in the Ipswich, Neponset, and North Rivers, as well as the upper Charles River would continue to decline as a result of projected industrial and residential growth of the surrounding regions. In many slower moving portions of metropolitan area waterways conditions approaching those described for the Lower Mystic Lakes and Lower Charles River Basin would ensue within a few decades. In freely flowing streams and marine waters, the degradation process would progress more slowly.

CONCEPT ONE

Positive Effects

Substantial volumes of treated wastewater will be added to several area streams, particularly from those treatment plants located at Marlboro Westerly (Assabet River); Sudbury (Sudbury River) and Concord (Concord River). This wastewater would contribute substantial flowages into each of the river systems during periods of dryness, promoting stability of the aquatic environments. Upgrading the level of sewage treatment in the upper Charles River (Milford, Medway and Medfield) would promote more stable dissolved oxygen conditions and encourage an increase in populations of such warm water game fish as largemouth bass. Newly constructed intercepting sewer systems should markedly alleviate pollution problems in certain local waterways (for example, Nagog Brook, in Concord).

Neutral Effects

In most of the area's major rivers, previously established littoral (shore) zones would be substantially reduced, and portions

of the flood plains which dry during low flow periods might be continually flooded. Aquatic vascular plants, such as pond weeds and various reedy plants, may appear as a result of new water levels and nutrients emanating from the sewage effluent.

Plans for the Ipswich River should have little or no impact on hydrological conditions of the river, although flows would be reduced slightly in the middle portion of the river's course. Any improvement in water quality in the Ipswich River would probably remain essentially unchanged from their present condition; factors (principally unauthorized discharges) not considered by this and other concepts, as presently constituted, will probably control the environmental destiny of the above named hydrological regions.

Negative Effects

Initial discharges of ammonia from the treatment plants may prove toxic to some sensitive organisms, especially with those effluents having pH values above 7.0. In addition, small excesses of chlorine in the discharged effluents will aggravate the locally toxic influence of ammonia on aquatic organisms (formation of chloramines).

Discharge of wastewater from the Marlboro Easterly treatment plant into Hagar Pond, and ultimately into Hobbs Brook, could elicit a substantial response in the form of nuisance algal blooms and weedy growth of vascular plants; the type of finfish existing under such conditions would be restricted to "rough" species, primarily the brown bullhead.

CONCEPT TWO

Positive Effects

In addition to those streams discussed under Concept One, the Neponset River (with two separate treatment plants at Canton, Massachusetts) would be included as a system benefiting from increased flows under Concept Two.

Neutral Effects

Effects would be the same as in Concept One, except for the impact on the Neponset River (see above, under "positive effects").

Negative Effects

With the enormous influence of the Framingham treatment plant on the Sudbury River (Table 15), discharge of substantial quantities of nutrients (cf. columns 3 and 4, Table 14) would accentuate eutrophication problems in this relatively sluggish stream. Similarly (but on a smaller scale), positive impacts on flow augmentation due to the Dedham plant on the Charles River would most likely be offset by the influence of nutrients from the treatment plant effluent. Effluent constituents from a plant at Watertown would enter what is essentially a lentic (lake-like) ecosystem. Such a system is so responsive that, at the proposed level of limited nutrient removal, excessive algal and other plant growth can be expected. Within the sphere of influence of the three treatment plants cited: Framingham, Dedham and Watertown, attempts to restore a viable recreational fishery would almost certainly yield negative or negligible results (e.g. edible fish would consist of such species as brown bullheads, carp, and a few bluegills or pumpkinseeds).

The local consequences of ammonia and chlorine discharges discussed under Concept One apply to Concept Two as well.

CONCEPT THREE

Positive Effects

Effects would be essentially as described under Concept One, excluding the impact on the upper Charles River (see below, under negative effects).

Neutral Effects

Effects would be essentially as described under Concept One.

Negative Effects

Diversion of water out of the upper Charles River watershed would result in a substantial reduction in river flow, accompanied by a reduction in suitable habitat for aquatic life.

Other negative effects are as described under Concept One.

CONCEPT FOUR

Positive Effects

Flow augmentation benefits described under Concept One likewise apply to Concept Four. The installation of a treatment plant at Woburn, which would greatly influence the Aberjona River, would actually be of benefit in partially alleviating present water quality problems related to industrial pollution and low flow. Projected ammonia levels in the effluent would represent a dilution from existing levels. Biological productivity would be restored to the river; finfish (at present, virtually non-existent) would probably consist mostly of the rough, forage and pan categories. Any species of game fish inhabiting the river would be unlikely.

Neutral Effects

Effects would be essentially the same as under Concept One. The positive impact on flow augmentation due to effluent discharge into the Neponset River would most likely be offset by combining the two Canton treatment plants into one, thereby accentuating local impacts, such as toxicity and eutrophication.

Negative Effects

Effects would be essentially the same as under Concept Two.

CONCEPT FIVE

Positive Effects

Where wastewater disposal is accomplished by means of land application, direct nutrient loading of study area waterways would be eliminated. The nutrients present in the effluent will be partially removed by the soil-plant system and diluted with groundwater. SI sites will provide the most reliable renovation. Diversion of a considerable portion of the wastewater load from the Boston metropolitan area to Cape Cod should substantially improve water quality in Boston Harbor and surrounding tide water areas.

Neutral Effects

Factors (such as separation of combined sewers, unauthorized discharges, and continued population growth) not taken into consideration by Concept Five will probably control the environmental destiny of the Mystic, Neponset and Ipswich Rivers.

If natural cover is allowed to remain on land sites designated for wastewater application, it is anticipated that a shift in plant species toward forms which require or tolerate moist soil conditions, would occur. However, a land site will normally be deliberately "prepared", by grading, filling (where required), and reseeding with suitable grass species, in order, to maximize the renovation effectiveness of the site.

Negative Effects

A substantial portion of the wastewater load will have been shifted from the Boston area to an RI site in Wareham, Massachusetts. The uncertain reliability of such a large scale processing of wastewater may have serious consequences for marine life in the Cape Cod Canal and immediately adjacent waters, and for nearby cranberry bogs. In the absence of sufficient information upon which to base an impact statement, extreme caution is advised in judging the practicability of this feature of Concept Five.

CONCEPT SIX

Positive Effects

Effects would be essentially the same as under concept one. Installation of the 2 MGD treatment facility at Woburn would stabilize flow of the Aberjona River. With control of industrial and non point discharges, a modest largemouth bass fishery might be established in the small ponds which intercept the stream.

Neutral Effects

Effects would be the same as under concept four. The treatment facility at Wellesley, which is unique to this concept would have the same local effects as the Canton plant, however an artificial fall at Charles River Village would serve as a re-aeration

buffer against downstream impacts.

Negative Effects

Effects would be the same as under concept one.

An additional approach to river basin planning would be to develop a program of systematic extension of riparian lands. This would be done by means of acquisition of the watershed. A given riparian investigation would be the quality of the water from the basin water

EVALUATION OF IMPACTS OF INDIVIDUAL TREATMENT FACILITIES

WASTEWATER TREATMENT PLANT AT FRAMINGHAM
(short term neutral; long term slightly negative)

A wastewater treatment plant situated on the Sudbury River at Framingham is not recommended, from an environmental standpoint, as a viable wastewater management alternative. Operation of this plant at effluent quality design criteria presently proposed would have negative consequences under normal late summer flow conditions. Compared to existing negative impacts, however, this influence of the treatment plant would be marginal. The key to this conclusion lies in an understanding of the ecological relationship between the river and extensive marshy meadows which continue from approximately one mile below the proposed treatment plant location to the Concord River.

Based on information gained from communication with Mr. Paul Hogan of the Massachusetts Division of Water Pollution Control, a general conceptualization of events contributing to the present deteriorated condition of the Sudbury River has been formulated. In spring, runoff from rains and melting ice and snow causes the surrounding marshes to become innundated. From late spring to mid summer the marshes are gradually drained. The drainage water carries with it a load of plant and other organic matter into the river. Microbial decomposition in the river creates a severe oxygen deficit. Data collected by the Massachusetts Division of Water Pollution Control Water Quality Survey showed that during July 1973 the river was nearly depleted of dissolved oxygen. By late August, algal blooms, stimulated by nutrients (Nitrogen and Phosphorus) released by the marshes produce enough oxygen to offset the deficit created by organic matter decomposition. Widely fluctuating dissolved oxygen concentrations (shown in the August 1973 data), in which supersaturation occurs by day and severe depletion by night, are attributed to the presence of a large algal population and other sources of decomposing organic matter.

Effluents from a wastewater treatment plant would provide an additional source of nutrients (especially nitrate from the nitrification of ammonia) to the marsh during periods of high water and to the algal bloom during the late summer, low water period. The biochemical oxygen demand of the wastewater effluent itself would be substantial under low flow conditions. The net result would be an increase in the production of organic matter which would add insult to the already injured river ecosystem.

An ecological approach to river basin planning would incorporate a program of eliminating existing sources of organic input created by human occupation of the watershed. A prime target for investigation would be the quality of leachate from the solid waste

disposal sites situated on either side of the Sudbury River in the vicinity of the Route 20 bridge. Leachate containing extremely high concentrations of incomplete decomposition products (high Biochemical Oxygen Demand) can escape into adjacent waterways. The potential negative impacts from these sites are of far greater magnitude than that of a tertiary sewage treatment plant such as the one planned for Framingham. This illustrates the fact that it is often difficult to separate wastewater management from other types of waste disposal considerations in attempting to improve the water quality of a river basin.

Short term impacts from the proposed Framingham wastewater treatment plant would be neutral or even slightly positive (stimulating marsh productivity). Long term impacts, however, would be negative. After a few years, it is probable that marsh development would accelerate to the point that the contribution of decaying vegetation would become objectionable.

In conclusion, compared to the present impacts of human activity on the aquatic and wetland ecosystem the negative impacts of a wastewater treatment plant at Framingham would be minor. Decreasing the nutrient output of the treatment plant by employing the best techniques of wastewater treatment available would probably reap small benefits. Augmentation of Sudbury River flow is not essential to the solution of existing water quality problems. From an ecological standpoint, sewerage from Southborough should be joined with Framingham rather than Marlborough Easterly, as the Hobbs Brook system will probably be overtaxed even without the addition of Southborough.

WASTEWATER TREATMENT PLANT AT WATERTOWN
(short term neutral; long term slightly negative)

Under existing conditions, the water quality of the lower Charles Basin is controlled primarily by urban runoff (storm drain discharge) and a highly saline layer of deoxygenated, nutrient-rich bottom water. As long as present conditions persist (and they will continue until drastic remedial action is taken), short term impacts of a wastewater treatment plant at Watertown would be of negligible influence. The treatment plant at Watertown is predicted to have a long term negative impact because continuous discharge of nutrients and BOD into what is essentially standing water would stimulate plant growth and eventually contribute to dissolved oxygen deficits.

The argument against siting a treatment plant at Watertown presumes that action to restore the Charles River Basin to its potential level of water quality will be taken at sometime in the future. A wastewater treatment plant at Watertown would not be a substitute for restorative measures. Assuming remedial action to restore the Charles River Basin is not implemented, siting a treatment plant at Watertown would have a neutral impact.

WASTEWATER TREATMENT PLANT AT DEDHAM
(short term slightly negative; long term negative)

Between the proposed site of the treatment plant at Dedham and the dams at Newton Upper Falls, the Charles River flows slowly through marshland, widening about 3/4 mile downstream to form Cow Island Pond and a smaller pond beyond. This section of the river has been described (Appalachian Mountain Club, 1973. New England Canoeing Guide) as "the most beautiful part of the Charles". The two ponds, however, are presently in danger of becoming choked with vegetation and already produce a substantial amount of organic material (John Erdman, Massachusetts Division of Water Pollution Control, personal communication).

A wastewater treatment plant at Dedham would probably accelerate plant growth and hasten the reduction of open water in the ponds. In addition, finfish populations would be placed under additional physiological stress during winter. It is a characteristic problem in eutrophic (nutrient enriched) ponds that decomposing organic matter depletes dissolved oxygen to critical levels when ice cover prevents reaeration. Thus, acceleration of eutrophication by a treatment plant may encourage the occurrence of winter fish kills in the Charles River ponds.

Existing problems associated with eutrophication could be greatly improved through elimination of upstream sources of organic pollution (see Section: Upper Charles River Wastewater Treatment Plants). A treatment plant at Dedham would be a hinderance in slowing the rate of eutrophication. Forcing this stretch of the river to handle a greater volume of organic material should be avoided.

To minimize oxygen demand and eutrophication pressures, wastewater effluent could be discharged at more than one point. One way to accomplish this would be to divert part of the effluent to the Neponset River via discharge into Mother Brook. Also, two treatment plants could be built to serve the design area, one upstream (e.g. at the Needham-Wellesley line) and one downstream (e.g. at Dedham, which discharges to Mother Brook). No matter what physical configuration is selected, effluent oxygen demand should be compatible with stream reaeration capacity immediately downstream from the discharge sites. The number of environmentally suitable options would increase with effluent quality. Higher treatment levels than presently envisioned may be required to retain the Dedham plant as a viable design component.

UPPER CHARLES RIVER WASTEWATER TREATMENT PLANTS (MILFORD, MEDWAY
AND MEDFIELD)
(short term positive; long term - slightly positive)

The Charles River between Milford and Medfield presently suffers

from intermittent water quality degradation due to various industrial and municipal waste discharges. The discharges are small enough and the stream flow rapid enough in certain places so that some oxygen recovery occurs. However, critical oxygen shortages frequently result in some of the ponds through which the river passes, particularly in Bellingham. Implementation of any of the concepts envisioned in the present wastewater management study would help greatly in alleviating local dissolved oxygen deficits due to inadequately treated sewage. A considerable increase in the population of warm water gamefish (particularly pickerel, the characteristic gamefish of eastern Massachusetts streams) should occur in the area. More importantly the stimulus toward eutrophication (overproduction) throughout the upper and middle portion of the river basin would be lessened. In the interest of minimizing wastewater inputs to Boston Harbor wherever there are environmentally sound alternatives to such disposal, the plans for constructing regional treatment plants at Medway and Medfield and upgrading the treatment level at Milford are recommended.

WASTEWATER TREATMENT PLANT AT MEDFORD

(short term negative; long term slightly negative)

Conditions existing in the Lower Mystic Basin are similar in many respects to conditions in the Lower Charles Basin. Each has been separated from tidal influences by a dam. Like the Charles River Basin, the Mystic Basin is essentially a standing water system, highly stratified and saline at the bottom. The salt marshes which used to exist along the banks have been filled in and the river channel dredged and straightened. A wastewater treatment plant situated on the Lower Mystic would, as in the Lower Charles, stimulate plant growth and, in the long term, contribute to dissolved oxygen deficits. This concern is inconsequential compared to the more serious impacts which will accrue if Alewife Brook (which enters the Mystic immediately above the proposed site of the treatment plant) is allowed to continue to receive quantities of untreated wastewater of various kinds. The future of the Mystic River as a suitable habitat for more than a few highly resistant species of aquatic life is dim.

WASTEWATER TREATMENT PLANT AT WELLESLEY, MASSACHUSETTS

(short term slightly negative; long term neutral)

It is assumed that the effluent from this treatment plant will be discharged into the Charles River between South Natick Dam and Cochrane Dam at Charles River Village. The river profile through this reach is nearly flat; hence stream flow is very sluggish. A rich variety of aquatic plants (including pond weeds and water lilies) abound, contributing to problems associated with eutrophication (enrichment) downstream. The condition of nutrient enrichment is illus-

trated by chlorophyll a and total phosphorous concentration values (20 to 30 $\mu\text{g/l}$ and 0.3 to 0.5 mgP/l respectively) surveyed by the Massachusetts Division of Water Pollution Control in the summer of 1973.

Since the Wellesley treatment plant is a component of a larger plan to upgrade sewage treatment in the entire Charles River Basin, it must be assumed that upstream point discharges (which now contribute substantially to local problems) will be abated; thus, hypothetically the river would return to a much less "disturbed" state than at present. Nutrients, BOD and other water quality variables would fall to a fraction of their present levels. However, water supply demand on aquifers associated with the hydrology of the Charles River will also increase. A report prepared by M. H. Frimpter for the U. S. Geological Survey warns that, given certain assumptions, namely: 1) no change in stream flow regulation 2) increased water consumption and 3) wastewater discharged outside the basin, flow in the river can be expected to approach zero for up to 55 days annually.

A trend towards diminished stream flow would greatly offset benefits in improved water quality due to pollution abatement since less water would be available for dilution. It is imperative that any wastewater discharged to the Charles River in the future be processed according to the best treatment technology available. If water for drinking purposes is to be drawn from ground water supplies associated with the river, denitrification should be instituted as well as phosphorous removal.

Given the possible future flow conditions in the Charles River it is nearly certain that a 30 MGD treatment plant at Wellesley would completely dominate the local hydrology of the Charles River in the vicinity of Wellesley, Needham and Dover under summer low flow conditions. The chief positive impact due to the discharge of treated wastewater would be flow augmentation. Considering the views of M. H. Frimpter, discharges from this plant might become critical to maintaining adequate flow through this flat section of the river. Consequences of not having augmented flow could be extensive development of marsh into what is presently the river channel, thereby obstructing boat passage through what is otherwise a fairly attractive reach. Extremely low water in the river would have an uncertain effect on aquatic life, but as insurance against dessication and over-heating of river pool remnants, it would be advantageous to have the treatment plant operating.

With the treatment plant in operation it is unlikely that water quality conditions could be expected to be much different than have existed in the past few years. At least there are outfall sites between south Natick Dam and Charles River Village which afford better opportunity for reaeration than downstream reaches, such as near Dedham.

Placement of the effluent outfall should be determined with the aid of a plug flow mathematical model to ensure optimum management of BOD and nutrients.

WASTEWATER TREATMENT PLANT AT WOBURN

(short term highly positive; long term slightly negative)

This design element has one very strong positive aspect: stabilization of flow in the Aberjona River. The water quality of the Aberjona River fluctuates erratically as does stream flow. During extremely dry periods, some portions of the stream bed may not have water. On a short term basis, treatment plant effluents could be very effective in flushing out and diluting the pockets of stagnant, deoxygenated water which have collected at various points in the stream.

The recipient of the pollutants flushed from the river, however, would be Upper Mystic Lake which is already badly in need of restoration. In addition, between the proposed treatment plant site and Upper Mystic Lake, there are several small ponds, two of which are known to experience severe oxygen deficits. Therefore, a treatment plant at Woburn could contribute to the oxygen deficit problem over the long term stringent pollution abatement standards applied to all waste sources entering the Aberjona, including the Woburn treatment plant. Concept six, which calls for a 94 percent reduction in the wastewater flow from this plant, would be the preferred configuration.

WASTEWATER TREATMENT PLANT AT CANTON

(short term neutral; long term negative)

The section of the Neponset River between the entrance of the East Branch and the Suffolk County Line presently does not suffer serious water quality degradation. The stream moves slowly through a wooded and marsh lowlands. The river is colored by effluents from the marshes, but there are no critical dissolved oxygen deficiencies, or unusually high contributions of suspended sediment. In contrast to the Sudbury River, the stream/marsh system of the Neponset River appears to be stabilized (i.e. the banks are well defined and flooding rarely occurs). The system could probably handle the wastewater load projected by the proposed Canton North Wastewater Treatment Plant, but inputs of the magnitude proposed for Canton (under Concept 4) or Canton South are not recommended. Loads of 25 to 30 MGD would probably lead in the long term to oxygen depletion such as is now experienced on the Sudbury River (see Section: Wastewater Treatment Plant at Framingham). Further, if the characteristic problems of an urbanized stream (which persist on the Neponset downstream from the Suffolk County line) were to be solved, large wastewater treatment plants upstream would be inappropriate.

RESULTS AND DISCUSSION

An attempt has been made to rank in importance those external factors affecting the potential impact of eight key wastewater treatment plants (Table 20). These external factors have been considered in three categories: biochemical oxygen demand (BOD), nutrients (primarily nitrogen and phosphorous), and toxicants.

Table 21 presents the overall impact assessment of discharging treated wastewater at each of the seven key treatment plant sites. In arriving at the assessment, consideration has been given to: 1) response of the stream to existing conditions; 2) quality and quantity of the proposed effluent in relation to stream flow and water quality; and 3) known and suspected "background" point and nonpoint sources of pollution. The degree to which the response of the stream depends on external factors (which are independent of the wastewater management alternatives considered in the EMMA study) is indicated by the "dependence level". Where the dependence level is low, the future of the waterway is primarily governed by management decisions not related to the proposed wastewater treatment plant; where the dependence level is high, the wastewater treatment plant is expected to play a substantial role (as shown in the impact assessment) in determining future water quality of the waterway.

TABLE 20. WASTE WATER TREATMENT PLANTS: RELATIVE INFLUENCE OF EXISTING BACKGROUND SOURCES*

TREATMENT PLANTS	BOD (OXYGEN DEFICIT)	NUTRIENTS (STIMULATE PRODUCTIVITY)	TOXICANTS (INHIBIT PRODUCTIVITY)
Framingham	Very high	high	low
Watertown	extremely high	extremely high	very high
Dedham	moderate	high	low
Wellesley	moderate	moderate	low
Upper Charles (Milford, Medway, Medfield)	Locally very high	Locally high	low
Medford	Very high (bottom waters)	high	high
Woburn	Locally very high	Locally very high	Locally high
Canton	Moderate to low	moderate	low

* The higher the background influence the more the long term impact of the WWTP is neutralized.

**TABLE 21. WASTE WATER TREATMENT PLANTS
SUMMARY OF IMPACTS ON AQUATIC ECOSYSTEM**

TREATMENT PLANTS	SHORT TERM	LONG TERM	DEPENDENCE LEVEL
Framingham	Neutral	Slightly negative	Low
Watertown	Neutral	Slightly negative	Low
Dedham	Slightly negative	Slightly negative	High
Wellesley	Slightly negative	Neutral	High
Upper Charles	Positive	Slightly positive	Moderately High
Medford	Neutral	Slightly negative	Low
Woburn	Highly positive	Slightly negative	Moderately High
Canton	Neutral	Negative	High

Except for the Merrimack River, eastern Massachusetts is drained by relatively small, slow-flowing streams characterized by many backwaters, marshes and meanders, not to mention man made impoundments. Because of small capacity and obstructions to flow, few sites on these streams are considered suitable for receiving and assimilating wastewater, except at the highest treatment level attainable. Given a very rigorous level of treatment, however, these plants could provide a stabilizing influence on stream flow.

Because a degree of uncertainty always remains with regard to quality control of such relatively large wastewater treatment plants, concepts two and four are seen as environmentally less desirable than concepts one and three. The major differences between concepts one and three are: 1) wastewater treatment plants in the upper Charles River are included in concept one and not in concept three; and 2) substantially less effluent is discharged through Nut Island wastewater treatment plant under concept one than in concept three. Because of these differences, concept one is preferred over concept three. In the first instance, the upper Charles treatment plants received a positive rating. In the second instance, the argument has been presented (see Upper Charles Wastewater Treatment Plants) that the wastewater load going to Boston Harbor should be kept to a minimum where environmentally feasible alternatives are available.

The feasibility of concept five (a land application concept) is uncertain. Evidence that wastewater percolate from secondary treatment will not seriously degrade ground water quality is as yet inconclusive for New England soils. Uncertainties persist concerning the capacity of New England soils (typically stony and/or droughtly) to renovate secondary effluent so that the percolate approaches reasonable water quality standards. In many cases the percolate would for a short time be diluted to satisfactory quality by groundwaters. In the long term, however, it is at least plausible that the equilibrium quality attained by the percolate would approach that of the applied effluent. Substantial man made alteration of the site characteristics and cultivation of certain crops would improve renovation capacity and forestall negative impacts of intermedia transfer of pollutants.

The main objection to concept five, however, is that a considerable portion of the EMMA Area wastewater load would be shifted from Boston Harbor to terrestrial sites in Plymouth County (Southeastern Massachusetts). The shift will not (in the absence of other remedial action) appreciably improve environmental conditions in Boston Harbor. In the absence of further study specific to the targeted areas, a more specific description of the nature of impacts on Plymouth County is not possible.

Concept six, which represents an optimization, employing a broad spectrum of assessment criteria (not environmental considerations alone), can be justified, from an environmental standpoint because of the strategic location of inland advanced wastewater treatment facilities to insure against future low flow problems. With regard to water quality impact, concept six is intermediate, between the more acceptable concepts one and three, and the concepts of lesser acceptability (two and four).

Even under the best conditions, in which the most environmentally acceptable configuration of wastewater disposal concepts is implemented, dramatic improvements in the quality and integrity of aquatic ecosystems, as presently constituted in the Eastern Massachusetts Metropolitan Area, cannot be reasonably anticipated in the space of a few years or decades. Rather than returning the aquatic environment to pristine conditions, which might have existed had civilization never come to eastern Massachusetts, the long term effects of implementing the management techniques discussed here would be to retard progressive deterioration of environmental quality, which otherwise would almost certainly continue apace.

No important biotic changes (e.g. in overall abundance, acquisition of new species, or loss of extant species) are expected regardless of the concept chosen. For the most part, factors which control the composition of wildlife communities in eastern Massachusetts are independent of management decisions considered here. Little weight need be given to terrestrial impact considerations, in deciding on the concept to be chosen, providing treatment levels of inland discharges are sufficiently high to satisfy stringent water quality standards.

Depending on locations, number, and size, treatment plants may, however, influence finfish community composition. Decentralization, (several small plants spaced at intervals along a stream instead of a very few large plants) favors low oxygen intolerant species (e.g. smallmouth bass). However, few of the treatment plants proposed in any of the six concepts, can be defined as small in relation to probable dry season flow in the receiving streams.

Implementation of the more acceptable wastewater management alternatives (concepts one, three or six) will help to re-establish balanced aquatic communities, in which game fish species consist of such warmwater residents as pickerel (*Esox* spp.) and bass (*Microp-terus* spp.), and (in the estuaries) striped bass (*Morone saxatilis*) and Alosids (shad, blueback herring and alewives). Concerning land application impacts, waterfowl may be attracted locally to rapid infiltration sites, and small game animals to the increased under-story vegetation characteristic of spray irrigation sites.

During the collection and analysis of data used in arriving at the preceding evaluations, it became obvious that a number of factors controlling the water quality of the streams in the study area were external to the treatment alternatives proposed. Such important considerations as urban runoff and leachate from solid waste disposal sites have either not been addressed at all or are not integrated into the alternative concept design. The impact of sludges, generated by the treatment plants and toxicants removed by industrial pretreatment have not been included in the impact assessment since the fate of these substances has not yet been revealed.

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